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A MODEL FOR THE ANALYSIS OF STOCKPILE/PRODUCTION BASE TRADEOFFS

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Meeting the wartime requirements for consumable materiel, particularly for ammunition, generally requires a stockpile for meeting initial needs, and a production base, for building the stockpile and also for supplying long-term demands if the war is of sufficiently great duration. During peacetime, stockpile and production base are complements--enlarged production bases result in a larger stockpile--but during wartime, they are (to a degree) substitute means of supplying the consumable.

Item 20 -- continued

This paper presents a linear programming model that determines the least cost mix of stockpile and production base necessary to satisfy wartime consumption. The model includes a build-up period during which production base is acquired and the stockpile is built, a steady-state period during which assets are at maintained post-build-up levels until the start of the war, and a mobilization-and-war period during which demand for the consumable must be met, either through stockpile depletion or through wartime production from previously acquired base.

The model is fast running and allows the user great flexibility in specifying the planning scenario.

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I. INTRODUCTION

A. BACKGROUND

Two mechanisms are available to provide a consumable, such as ammunition, for a possible future war:

(1) A *stockpile* is generally established to meet the immediate (and usually heavy) demand in the early stages of the war. Stockpiles are generally very responsive; that is, they are quickly made available, but unless very large, they can be eventually exhausted if the war endures for any length of time.

(2) A *production base* for manufacturing the consumable can provide for the requirements of a protracted war. However, because of the length of time required to bring a production base into operation, production bases are inadequate to satisfy demand early in the war.

It is therefore generally accepted that both a stockpile and a production base are necessary to satisfy wartime requirements--the stockpile for the early stages of the war, the production base later on. During the intermediate stages of the war, trade-offs can be made to some extent--a larger stockpile can postpone the need for bringing the production base into play, thus permitting a less reactive and possibly less costly base, whereas a production base that can quickly be brought to wartime levels of production can reduce the size of the required stockpile. In this sense stockpile and production base are partially substitutable during wartime. + peacetime

Too simplified

During peacetime, however, stockpile and production base are complementary. The larger the stockpile being established, the larger is the production base needed to produce it.

Because of these relationships, stockpile and production base are inextricably linked. One cannot determine the correct stockpile size without considering the production base nor can one specify the production base without accounting for the stockpile. It follows, therefore, that if one wishes to optimally fix, by some measure of effectiveness, the sizes of the stockpile and production base to satisfy the requirements of some projected war, one must consider them jointly and balance their respective features and costs. Among other things, one must attend to such attributes as responsiveness to demand, holding and production costs, deterioration rates, budget limitations, and so forth, in order to determine the best stockpile/production base mix.

To assist in this determination, this paper presents the IDA Stockpile/Production Base Model (hereafter the S/PB model), an optimizing computer model that determines the least costly combination of stockpile and production base required to meet a specified wartime consumption curve. The model explicitly considers such parameters as planning and warning periods, deterioration rates, cost discounting factors, and so forth. Using the methods of linear programming, the model determines a globally optimal schedule of production base purchases and consumable production. The model can also be used to find the best combination of two alternative production bases for the same consumable. The model examines a single type of consumable at a time, but can be applied to many different types.

B. MODEL OVERVIEW

The S/PB model is based on a simple time step model wherein the variables represent activities at certain times. However, in order to combine the peacetime planning period, wherein

stockpile and production base are acquired in an orderly fashion, with the wartime period, where they must be managed to deal with rapidly changing requirements, the basic, or core, time step model has been modified to account for those separate periods of time.

The first period--what we call the Build-up period--is characterized by the smooth acquisition of assets. Typically lasting many years, this period includes the purchase of production base to be used to build the stockpile, the purchase of the production base to be stored for later, wartime, use, and the creation of the stockpile from production base producing at peacetime rates. Pre-existing assets, of course, are considered in this period.

We do not assume that the war necessarily begins conveniently right after the Build-up period. Although supposing the war will occur is necessary to establish the consumption requirements, whether it actually occurs, and when, is not at all certain. In order to address these types of uncertainties, the model allows an interval of variable (user-specified) length called the Steady-state period which separates the onset of the war from the conclusion of the Build-up period. During the Steady-state period, resources acquired during the Build-up period are maintained at constant levels. The long-term peacetime costs of stockpile and production base may be accounted for during this period.

The Steady-state period terminates with the beginning of industrial mobilization, which marks the beginning of the Mobilization/War period. This period most closely resembles the core time-step model and during this period the production base previously acquired is typically brought to wartime production rates and the consumable is produced by the production base as well as drawn down by the wartime requirements. Additional production base may be acquired, if needed, and time

lags in changing production rates, as well as shipping the consumable from where it is produced to the theater, are carefully kept track of.

Throughout these three periods, the costs of all activities are accounted for and the objective of the model is to arrange these activities during the Build-up, Steady-state, and Mobilization/War periods so as to minimize the total costs.[1]

There are various optional constraints, such as budget constraints, that can be imposed by the user who wishes to explore a range of policy options.

Chapter II supplies the mathematical formulation of the model. Chapter III is a User's Guide. Appendix A contains Glossaries of Input Parameters and Model Variables and Appendix B is a FORTRAN listing of the model as implemented at IDA.

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[1]At the user's discretion, wartime costs can be included or omitted in this total.

II. MATHEMATICAL FORMULATION

The S/PB model represents activities over time--from the beginning of an acquisition period, during which capital equipment for the production base is acquired and the stockpile is prepared, through a period from the end of the build-up to the beginning of the mobilization, during which the various components of the model are kept at constant levels, to a final period of mobilization and war. These are called, respectively, the Build-up, the Steady-state and the Mobilization/War periods. While each of these periods is an embodiment of essentially the same activities, the different emphasis placed on each period makes it convenient to model the three periods in quite different ways.

In order to assist the reader in comprehending not only the entire model, but also the differences and similarities among the three periods that partition the model, we adopt a two step approach. We first define what we shall call a "core model" which comprises the fairly simple equations that specify the interactions among model components without regard to initial and final conditions and ignoring the specific assumptions that distinguish the three periods. Once the core model has been described, it provides the background for the three periods of the S/PB model. We begin by discussing the components common to the core and S/PB models.

For simplicity of exposition, we will refer to the consumable as ammunition. Bear in mind, however, that this is only one form of consumable and that the model has applications to other wartime consumables.

A. COMPONENTS

The fundamental components shared by the core and S/PB models are these:

(1) Capital equipment for producing ammunition
(2) A domestic ammunition stockpile
(3) An in-theater ammunition stockpile supplied from the domestic stockpile
(4) Domestic and in-theater demands for ammunition.

cold warm hot

The capital equipment may be in one of three states. It may be in storage and not producing ammunition, or it may be producing ammunition at a moderate rate (as during peacetime) or at a high rate (as during mobilization and war). These three states we will refer to as cold, warm, and hot, respectively. Each state entails different costs, both of maintaining the capital, and of producing ammunition in the case of warm and hot ammunition. Capital may be transferred among states, although this incurs additional costs as well as time delays.

layaway? startup?

In order for the model to distinguish between, for instance, expensive, highly automated equipment that may be very responsive to wartime demands, and less responsive, less costly equipment, or between other capital alternatives (e.g., capital equipment with differing productivities), the model accommodates two types of capital for producing a single ammunition type, which we will refer to as type 1 and type 2 capital. These types of capital are distinguishable only through the values of the inputs that pertain to them. Otherwise the model handles them in identical ways.

Ammunition produced by warm and hot type 1 and type 2 capital equipment enters the domestic stockpile, from which some of it may be shipped to the in-theater stockpile. The domestic stockpile is used to satisfy domestic demand while in-theater demand draws on the in-theater stockpile.

Capital equipment in all states and ammunition in both stockpiles are subject to deterioration; that is, over a period of time, a certain fraction of the resources becomes useless.

The relationships among these components are depicted in Figure 1. New capital of either type enters the model via purchases which feed directly into cold stock. From cold stocks, capital may be transferred to warm or hot stocks and capital in warm stocks may be transferred to hot or back to cold stocks. Hot capital may transfer to either cold or warm stocks. Note that there is no transfer between type 1 and type 2 capital. Over time, all six categories of capital suffer deterioration, as we have already said, although this is not depicted on the diagram.

Ammunition produced by warm and hot capital stocks enters the domestic stockpile from which some is removed to satisfy domestic demand, some is lost to deterioration, and some is transferred to the in-theater stockpile. The mechanism by which ammunition is transported from the domestic to the in-theater stockpile, be it airlift, sealift, or some other means, will be referred to as the "pipeline." Part of the in-theater stockpile goes to satisfy in-theater demand and another fraction deteriorates. The remainder is held against future requirements. The domestic and in-theater stockpiles are distinguished primarily to model the effect of time lag in the pipeline; that is, the delay between when ammunition is produced and when it is available in the theater, and also to account for pipeline quantity constraints and upper bounds on the in-theater stockpile. As in the case of capital equipment, the deterioration of the domestic and in-theater stockpiles is not depicted in Figure 1.

Each transfer of resource, whether capital equipment or ammunition, incurs a time delay. Equipment purchased may not appear in cold stocks until after a suitable period of time. Equipment transferred from cold to warm or hot stocks cannot produce until after a suitable period of time while equipment

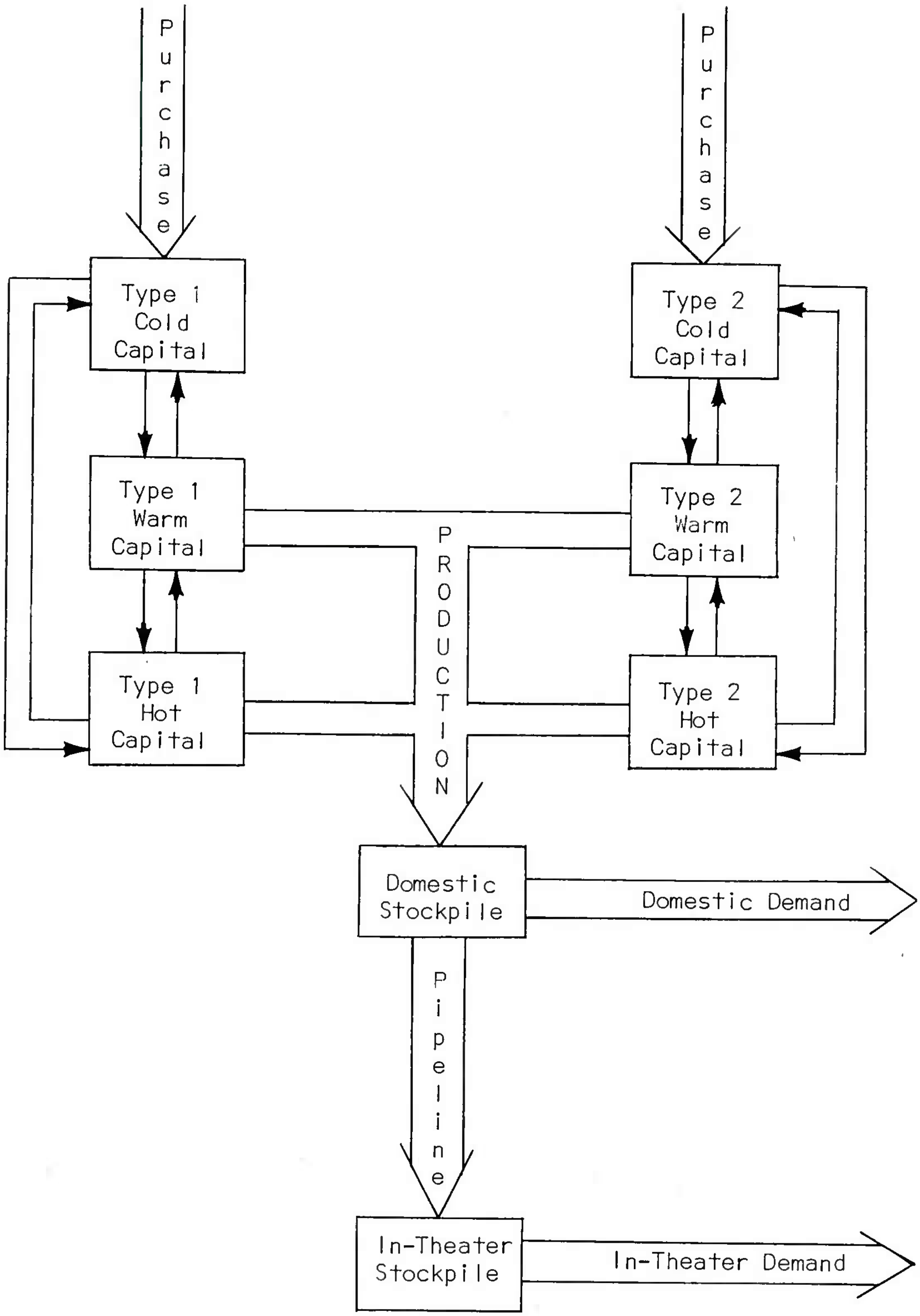

Figure 1. SCHEMATIC OF MODEL

going from warm to hot requires a certain time to reach the hot level, during which it continues to produce at the warm rate. In a like manner, ammunition going from the domestic to the in-theater stockpile may be thought of as being in the pipeline for a certain length of time.

Although not explicitly represented in Figure 1, each activity depicted has an associated cost. Costs apply to the holding and transfer of resources, as well as the purchase of capital and the production of ammunition.

B. TIME PERIODS

As discussed previously, the components are manipulated over a time span that comprises a Build-up period, a Steady-state period, and a Mobilization/War period. In order to model the dynamics of this manipulation over time, the three periods are divided into various numbers of equal length time steps. The time step is the fundamental unit of time--no action can take less than this time unit to execute. For instance, if the time step is one month, then all the time delays in the model must be multiples of one month, as must be the lengths of the three periods. A typical time span under investigation might have a Build-up period of five years (60 time steps), and a Steady-state period of 15 years (180 time steps) and a Mobilization/War period of two years (24 time steps). The time required for purchased capital to enter cold stocks may be 24 months (24 time steps); for capital to transfer from cold to warm stocks, six months (6 time steps); and so forth. The length of the time step, as well as the duration of the three periods, is flexible and determined by the user of the S/PB model.

C. THE CORE MODEL

The core model describes the interactions of the model components without regard to initial and terminal conditions. In addition, the differences among the Build-up, Steady-state

and Mobilization/War periods are suppressed. The core model describes how levels of resources at any given time step relate to the levels of resources at other time steps without the complicating distinctions among periods. The S/PB model is based entirely on the core model, although the assumptions implicit in each period alter the basic mathematical expressions considerably.

We will index the time steps using the integer t, which, one may assume, takes on values between $-\infty$ and ∞ (because we have ignored initial and terminal conditions). The variables of the core model are listed and defined below. Because of our assumptions, note that there are a countably infinite number of variables in the core model, which makes it impractical to employ, although this does not decrease its pedagogical usefulness. The units of measurement implicit in each variable are not important as long as a consistent standard is adopted. Finally, we employ FORTRAN-like variable names. Although this is somewhat cumbersome, these variable names parallel those in the computer implementation of the S/PB model and, therefore, once used to these variable names, the reader will find it easier to learn the S/PB model. All the variables are assumed nonnegative.

1. Variables

a. Capital Stocks

C1(t) = the amount of type 1 cold capital stocks held during time step t

C2(t) = the amount of type 2 cold capital stocks held during time step t

W1(t) = the amount to type 1 warm capital stocks held during time step t

W2(t) = the amount of type 2 warm capital stocks held during time step t

H1(t) = the amount of type 1 hot capital stocks held during time step t

H2(t) = the amount of type 2 hot capital stocks held during time step.

b. Ammunition Stockpile

S(t) = the amount of ammunition held in the domestic stockpile during time step t

SP(t) = the amount of ammunition held in the in-theater stockpile during time step t.

2. Transfer Variables

Note: In all cases, the transfers of assets described below are initiated during time step t and concluded during a future time step.

TCW1(t) = the amount of type 1 capital transferred from cold to warm stocks beginning during time step t

TCW2(t) = the amount of type 2 capital transferred from cold to warm stocks beginning during time step t

TCH1(t) = the amount of type 1 capital transferred from cold to hot stocks beginning during time step t

TCH2(t) = the amount of type 2 capital transferred from cold to hot stocks beginning during time step t

TWH1(t) = the amount of type 1 capital transferred from warm to hot stocks beginning during time step t

TWH2(t) = the amount of type 2 capital transferred from warm to hot stocks beginning during time step t

THW1(t) = the amount of type 1 capital transferred from hot to warm stocks beginning during time step t

THW2(t) = the amount of type 2 capital transferred from hot to warm stocks beginning during time step t

THC1(t) = the amount of type 1 capital transferred from hot to cold stocks beginning during time step t

THC2(t) = the amount of type 2 capital transferred from hot to cold stocks beginning during time step t

TWC1(t) = the amount of type 1 capital transferred from warm to cold stocks beginning during time step t

TWC2(t) = the amount of type 2 capital transferred from warm to cold stocks beginning during time step t

PIPE(t) = the amount of ammunition transferred from the domestic to the in-theater stockpile beginning during time step t.

3. Capital Purchase Variables

PC1(t) = the amount of type 1 capital purchased during time step t

PC2(t) = the amount of type 2 capital purchased during time step t.

4. Structural Equations

The structural equations of the core model are given below. They describe the interactions over time of the stockpiles and capital stocks. Parameters required by the core model are described following the equations in which they are introduced.

a. Cold Equipment Stocks

(1) $$C1(t) = C1(t-1) \cdot (1-DC1) + PC1(t-LP1) + TWC1(t-LWC1) + THC1(t-LHC1) - TCH1(t) - TCW1(t)$$

(2) $$C2(t) = C2(t-1) \cdot (1-DC2) + PC2(t-LP2) + TWC2(t-LWC2) + THC2(t-LHC2) - TCH2(t) - TCW2(t)$$

where

DC1 = the fraction of type 1 cold stocks lost to deterioration during one time step

DC2 = the fraction of type 2 cold stocks lost to deterioration during one time step

LP1 = the number of time steps from the time type 1 capital is purchased until it is delivered to cold stocks

LP2 = the number of time steps from the time type 2 capital is purchased until it is delivered to cold stocks

LWC1 = the number of time steps required to transfer type 1 capital from warm to cold stocks

LWC2 = the number of time steps required to transfer type 2 capital from warm to cold stocks

LHC1 = the number of time steps required to transfer type 1 capital from hot to cold stocks

LHC2 = the number of time steps required to transfer type 2 capital from hot to cold stocks.

Equations (1) and (2) are easily interpreted. For instance, Equation (1) states that the amount of type 1 cold capital held during time step t is the total of (i) the amount held during time step t-1, corrected for deterioration, (ii) plus the amount of type 1 capital purchased LP1 time steps previously, (iii) plus the amount of type 1 capital transferred from warm to cold stocks beginning LWC1 time steps previously, (iv) plus the amount of type 1 capital transferred from hot to cold stocks beginning LHC1 time steps previously, (v) minus the amount of type 1 capital transferred from cold to warm stocks beginning during this time step, (vi) minus the amount of type 1 capital transferred from cold to hot stocks beginning during this time step. An analogous explanation applies to Equation (2).

Because the remaining structural equations closely resemble Equations (1) and (2), being accountings of the flows of resources, we leave it to the reader to supply most of the interpretations of the remaining equations.

b. <u>Warm Equipment Stocks</u>

(3) $$W1(t) = W1(t-1) \cdot (1-DW1) + TCW1(t-LCW1) + THW1(t-LHW1) - TCW1(t) - TWH1(t)$$

$$W2(t) = W2(t-1) \cdot (1-DW2) + TCW2(t-LCW2) + THW2(t-LHW2) - TWC2(t) - TWH2(t)$$

where

DW1 = the fraction of type 1 warm stocks lost to deterioration during one time step

DW2 = the fraction of type 2 warm stocks lost to deterioration during one time step

LCW1 = the number of time steps required to transfer type 1 capital from cold to warm stocks

LCW2 = the number of time steps required to transfer type 2 capital from cold to warm stocks

LHW1 = the number of time steps required to transfer type 1 capital from hot to warm stocks

LHW2 = the number of time steps required to transfer type 2 capital from hot to warm stocks.

c. <u>Hot Equipment Stocks</u>

(5) $$H1(t) = H1(t-1) \cdot (1-DH1) + TCH1(t-LCH1) + TWH1(t-LWH1) - THC1(t) - THW1(t)$$

(6) $$H2(t) = H2(t-1) \cdot (1-DH2) + TCH2(t-LCH2) + TWH2(t-LWH2) - THC2(t) - THW2(t)$$

where

DH1 = the fraction of type 1 hot stocks lost to deterioration during one time step

DH2 = the fraction of type 2 hot stocks lost to deterioration during one time step

LCH1 = the number of time steps required to transfer type 1 capital from cold to hot stocks

LCH2 = the number of time steps required to transfer type 2 capital from cold to hot stocks

LWH1 = the number of time steps required to transfer type 1 capital from warm to hot stocks

LWH2 = the number of time steps required to transfer type 2 capital from warm to hot stocks.

d. <u>Domestic Ammunition Stockpile</u>

(7) $$S(t) = S(t-1) \cdot (1-DS) + \frac{W1(t)}{KW1} + \frac{W2(t)}{KW2} + \frac{H1(t)}{KH1} + \frac{H2(t)}{KH2} + \sum_{t-LWH1<s\leq t} \frac{TWH1(s)}{KW1} + \sum_{t-LWH2<s\leq t} \frac{TWH2(s)}{KW2} - PIPE(t) - DD(t)$$

where

DS = the fraction of the domestic ammunition stockpile lost to deterioration during one time step

KW1 = the capital to output ratio for type 1 warm capital (see discussion below)

KW2 = the capital to output ratio for type 2 warm capital (see discussion below)

KH1 = the capital to output ratio for type 1 hot capital (see discussion below)

KH2 = the capital to output ratio for type 2 hot capital (see discussion below)

DD(t) = the domestic demand for ammunition during time step t.

The core model represents the production of ammunition through the capital to output ratios KW1, KW2, KH1, and KH2. Each ratio represents the amount of capital of the specified category required to produce one unit of ammunition, so that the expression

$$\frac{W1(t)}{KW1} + \frac{W2(t)}{KW2} + \frac{H1(t)}{KH1} + \frac{H2(t)}{KH2}$$

$$+ \sum_{t-LWH1<s\leq t} \frac{TWH1(s)}{KW1} + \sum_{t-LWH2<s\leq t} \frac{TWH2(s)}{KW2}$$

represents the total amount of ammunition produced during time step t. The final two terms represent production at warm rates by capital being transferred from warm to hot stocks. The summations account for the transfer time delay.

e. In-Theater Ammunition Stockpile

(8) SP(t) = SP(t-1) · (1-DSP) + PIPE(t-LPIPE) - FD(t)

where

DSP = the fraction of the in-theater ammunition stockpile lost to deterioration during one time step

LPIPE = the number of time steps required to transfer ammunition from the domestic to the in-theater stockpile

FD(t) = the in-theater demand for ammunition during time step t.

5. Costs

The user's goal in employing the S/PB model is to determine values for the variables that are consistent with the structural equations, that satisfy additional constraints of the user's choosing, and that minimize some objective function. The objective function we choose is that which represents the total cost of all activities represented by the model, discounted over time. To be consistent with our two step approach to the description of the S/PB model, we provide, in this section, an objection function for the core model.

We begin by listing, for each variable of the core model, the name of the parameter describing the cost associated with that variable and the definition of the cost. Note that some variables, specifically W1(t), W2(t), H1(t), and H2(t), are associated with more than one cost, and that some costs, namely, VPW1 and VPW2, are associated with more than one variable.

Variable	Cost Parameter	Definition
PC1(t)	VPC1	The cost of purchasing one unit of type 1 capital
PC2(t)	VPC2	The cost of purchasing one unit of type 2 capital
C1(t)	VC1	The cost of maintaining one unit of type 1 capital in cold stocks for one time step.
C2(t)	VC2	The cost of maintaining one unit of type 2 capital in cold stocks for one time step
W1(t)	VW1	The cost of maintaining one unit of type 1 capital in warm stocks for one time step
W2(t)	VW2	The cost of maintaining one unit of type 2 capital in warm stocks for one time step

Variable	Cost Parameter	Definition
$\frac{W1(t)}{KW1}$, $\frac{TWH1(t)}{KW1}$	VPW1	The cost of producing one unit of ammunition from type 1 warm stocks.
$\frac{W2(t)}{KW2}$, $\frac{TWH2(t)}{KW2}$	VPW2	The cost of producing one unit of ammunition from type 2 warm stocks.
H1(t)	VH1	The cost of maintaining one unit of type 1 capital in hot stocks for one time step
H2(t)	VH2	The cost of maintaining one unit of type 2 capital in hot stocks for one time step
$\frac{H1(t)}{KH1}$	VPH1	The cost of producing one unit of ammunition from type 1 hot stocks
$\frac{H2(t)}{KH2}$	VPH2	The cost of producing one unit of ammunition from type 2 hot stocks
S(t)	VS	The cost of maintaining one unit of ammunition in the domestic stockpile for one time step
SP(t)	VSP	The cost of maintaining one unit of ammunition in the in-theater stockpile for one time step
PIPE(t)	VPIPE	The cost of transferring one unit of ammunition from the domestic to the in-theater stockpile
TCW1(t)	VCW1	The cost of transferring one unit of type 1 capital from cold to warm stocks
TCW2(t)	VCW2	The cost of transferring one unit of type 2 capital from cold to warm stocks
TCH1(t)	VCH1	The cost of transferring one unit of type 1 capital from cold to hot stocks
TCH2(t)	VCH2	The cost of transferring one unit of type 2 capital from cold to hot stocks
TWH1(t)	VWH1	The cost of transferring one unit of type 1 capital from warm to hot stocks
TWH2(t)	VWH2	The cost of transferring one unit of type 2 capital from warm to hot stocks
TWC1(t)	VWC1	The cost of transferring one unit of type 1 capital from warm to cold stocks

Variable	Cost Parameter	Definition
TWC2(t)	VWC2	The cost of transferring one unit of type 2 capital from warm to cold stocks
THC1(t)	VHC1	The cost of transferring one unit of type 1 capital from hot to cold stocks
THC2(t)	VHC2	The cost of transferring one unit of type 2 capital from hot to cold stocks
THW1(t)	VHW1	The cost of transferring one unit of type 1 capital from hot to warm stocks
THW2(t)	VHW2	The cost of transferring one unit of type 2 capital from hot to warm stocks

Note that the above cost parameters are independent of time--they are the same for all time steps. To allow for inflation and also opportunity costs, the core model permits these costs to be discounted over time. Let the parameter R denote the discount factor that applies to a single time step. Then the cost of an activity for a single time step is $(1+R)^{-1}$ times the cost of that activity for the previous time step. For instance, if the cost of maintaining one unit of ammunition in the domestic stockpile during time step t is VS, then the cost of maintaining one unit of the domestic stockpile during time step (t+1) is VS/(1+R), and the cost during time step (t+2) is $VS/(1+R)^2$.

For the core model, we will arbitrarily select time t = 0 for the base costs so that the cost of an activity during time step t is the cost parameter times $(1+R)^{-t}$.

We present below the objective function of the core model. Because of the core model's infinite time horizon, one should view this function as a formal expression only, since for actual variables and parameters it may well be infinite.

$$
(9) \quad \sum_{\text{all } t} \frac{1}{(1+R)^t} \cdot \Big\{ PC1(t) \cdot VPC1 + PC2(t) \cdot VPC2 + C1(t) \cdot VC1
$$

$$
+ C2(t) \cdot VC2 + W1(t) \cdot \left(VW1 + \frac{VPW1}{KW1} \right) + W2(t) \cdot \left(VW2 + \frac{VPW2}{KW2} \right)
$$

$$
+ H1(t) \cdot \left(VH1 + \frac{VPH1}{KH1} \right) + H2(t) \cdot \left(VH2 + \frac{VPH2}{KH2} \right) + S(t) \cdot VS
$$

$$
+ SP(t) \cdot VSP + PIPE(t) \cdot VPIPE + TCW1(t) \cdot VCW1
$$

$$
+ TCW2(t) \cdot VCW2 + TCH1(t) \cdot VCH1
$$

$$
+ TCH2(t) \cdot VCH2 + TWH1(t) \cdot \left(VWH1 + \frac{VPW1}{KW1} \cdot \sum_{i=1}^{LWH1} \frac{1}{(1+R)^{i-1}} \right)
$$

$$
+ TWH2(t) \cdot \left(VWH2 + \frac{VPW2}{KW2} \cdot \sum_{i=1}^{LWH2} \frac{1}{(1+R)^{i-1}} \right)
$$

$$
+ TWC1(t) \cdot VWC1 + TWC2(t) \cdot VWC2
$$

$$
+ THC1(t) \cdot VHC1 + THC2(t) \cdot VHC2 + THW1(t) \cdot VHW1
$$

$$
+ THW2(t) \cdot VHW2 \Big\} .
$$

This concludes our discussion of the core model. Although not implementable, it is easily comprehendible. Note that all the structural equations as well as the objective function are linear in all the variables. By imposing additional assumptions on the interactions defined by the core model, we will create the S/PB model, to which we will append some additional constraints.

D. THE STOCKPILE/PRODUCTION BASE MODEL

Although it is feasible to structure the S/PB model as a completely time-stepped model, similar to the core model, the result of long Build-up, Steady-state and Mobilization/War periods combined with reasonably short time steps would be a model much too unwieldy for analytical purposes. Indeed, such a model probably could be handled by only the largest computers.

We therefore have built the S/PB model as a hybrid, wherein the Build-up and Steady-state periods have been simplified by aggregation so that all the activities during those periods, no matter how long they are, can be described by comparatively few variables. This allows us to expand the detail of the model during the Mobilization/War period where a true time-stepped approach is used.

1. The Build-Up Period

The Build-up period is distinguished by the acquisition of resources: capital equipment and ammunition. These are added to resources already owned. We denote by NPURCH the number of time steps in the Build-up period. The assumptions behind the Build-up period include:

(1) The demand for ammunition during this period is constant over time.

(2) The domestic and in-theater ammunition stockpiles are essentially indistinguishable; that is, they may be considered as a single ammunition reservoir.

(3) Because the Build-up period occurs during peacetime, we assume that ammunition is produced at a single production rate (presumably the most economical rate). Therefore only cold stocks (for storage) and warm stocks (for production) are active during the Build-up period. Hot stocks do not actively appear.

(4) The longer time delays involved in the acquisition of new capital are taken into account while the smaller time delays involved in transferring capital between producing and nonproducing states are disregarded, except for the purpose of discounting costs.

In order to make the description and equations simpler, we will first describe the Build-up period as if there were no time delay in acquiring new capital and then in the final part of this section we will describe the effects of considering that time delay.

We divide the purchases of capital into two categories. The first category is that capital purchased for eventual use,

but which, for the Build-up period, will be maintained in cold stocks. The second category is that capital purchased for the purpose of creating the ammunition stockpile and for satisfying demand during this period. This latter category of capital will therefore be maintained in warm stocks. The distinct purposes of these categories of capital suggest that there should be no transfer of capital between them during the Build-up period, and we will, in fact, assume this. With this idea in mind, we will refer to the "purchase of cold capital" as the purchase of that capital intended for cold stocks, and to the "purchase of warm capital" as the purchase of that capital intended for warm stocks. Recalling the core model, it is evident that the "purchase of warm capital" involves two steps: the purchase of capital and its transfer from cold to warm stocks.

a. Purchase of Cold Capital

In order to succeed in our effort to limit the number of variables required to describe the Build-up period, we must select, *a priori*, a family of purchase trends over time. For the purchase of cold capital, we allow only linear purchase patterns. Examples of linear purchase patterns for type 1 capital are depicted in Figure 2.

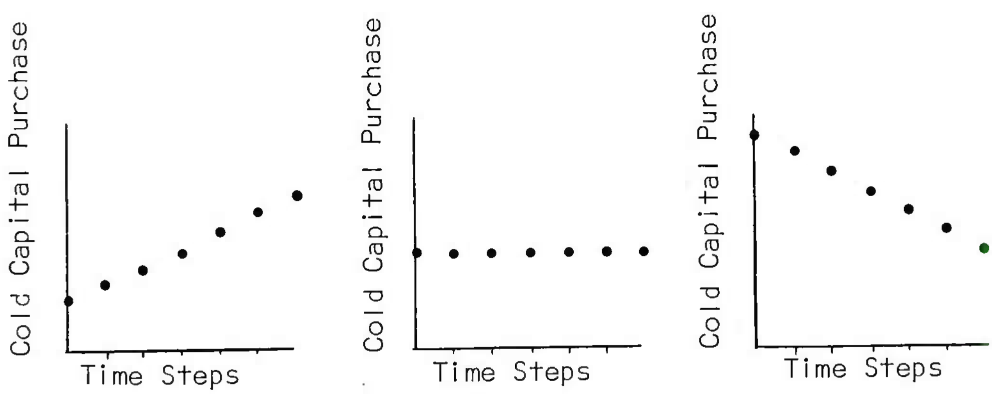

Figure 2. LINEAR PURCHASE PATTERNS

The horizontal axes in Figure 2 show the time steps of the Build-up period. The vertical axes all measure the amount of type 1 capital purchased. It is clear why these are called linear purchase patterns. Figure 3 illustrates a purchase pattern not permitted.

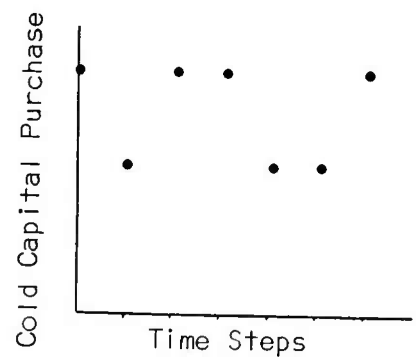

Figure 3. DISALLOWED PURCHASE PATTERN

For the purpose of this discussion, let us assume that the first time step of this period is denoted by t = 1. The last is therefore t = NPURCH. The S/PB model variables that describe the family of cold capital purchase patterns are:

BC1 = the amount of type 1 cold capital purchased at time step t = 1

BC2 = the amount of type 2 cold capital purchased at time step t = 1

SLPPC1 = the positive component of the slope of the type 1 cold capital purchase pattern

SLPNC1 = the negative component of the slope of the type 1 cold capital purchase pattern

SLPPC2 = the positive component of the slope of the type 2 cold capital purchase pattern

SLPNC2 = the negative component of the slope of the type 2 cold capital purchase pattern.

The type 1 cold capital purchase at any time step t of

the Build-up period is therefore

$$BC1 + (t-1) \cdot (SLPPC1-SLPNC1)$$

and, similarly, the type 2 cold capital purchased at any time step t is

$$BC2 + (t-1) \cdot (SLPPC2-SLPNC2) .$$

The reason we require the slopes be divided into positive and negative components is to maintain the nonnegativity of all model variables.

The total amount of cold capital at the end of the Build-up period is the sum of all the purchases plus any original cold capital existing before time step t = 1. Note that capital purchased during different time steps suffers varying deterioration by the end of the Build-up period. Capital purchased during time step t = 1 as well as original capital has deteriorated for (NPURCH-1) time steps while capital purchased during time step t = NPURCH has not deteriorated at all by the end of the Build-up period.

Table 1 illustrates how the total cold capital at the end of the Build-up period is determined. In this table B stands for BC1, S for (SLPPC1-SLPNC1) and O for the original type 1 cold capital.

The term DC1, or course, is the type 1 cold capital deterioration factor we have already encountered in the core model.

A similar progression applies to type 2 cold capital purchases.

Let

OCOLD1 = the amount of original type 1 cold capital and
OCOLD2 = the amount of original type 2 cold capital.

Table 1. COLD CAPITAL ACCRUAL

Time Step	Capital Purchased	Capital on Hand
1	B	0+B
2	B+S	B+S + (1-DC1)(0+B)
3	B+2S	$B+2S + (1-DC1)(B+S) + (1-DC1)^2(0+B)$
4	B+3S	$B+3S + (1-DC1)(B+2S) + (1-DC1)^2(B+S) + (1-DC1)^3(0+B)$
.	.	
.	.	
.	.	
NPURCH	B+(NPURCH-1)·S	$B\left[\sum_{i=1}^{NPURCH} (1-DC1)^{i-1}\right] + S\left[\sum_{i=1}^{NPURCH-1} i(1-DC1)^{NPURCH-1-i}\right]$

Then the amounts of type 1 and type 2 cold capital at the end of the Build-up period are given by

$$(10)\quad BC1\cdot\left[\sum_{i=1}^{NPURCH} (1-DC1)^{i-1}\right] + (SLPPC1-SLPNC1)\cdot\left[\sum_{i=1}^{NPURCH-1} i(1-DC1)^{NPURCH-1-i}\right]$$

$$+\ OCOLD1\cdot(1-DC1)^{NPURCH-1}$$

$$(11)\quad BC2\cdot\left[\sum_{i=1}^{NPURCH} (1-DC1)^{i-1}\right] + (SLPPC2-SLPNC2)\cdot\left[\sum_{i=1}^{NPURCH-1} i(1-DC2)^{NPURCH-1-i}\right]$$

$$+\ OCOLD2\cdot(1-DC2)^{NPURCH-1}$$

b. Purchase of Warm Capital

Because the purchase of warm capital is tied to the production of ammunition, the S/PB model allows not only the linear purchase patterns already discussed, but also additional purchases for the first time step only. The motivation behind this additional degree of freedom is that warm capital purchased during the latter stages of the Build-up period can produce

ammunition for only a relatively short time. Therefore, the model allows one to look at scenarios in which the maximum use can be obtained from warm capital; that is, when all the warm capital is purchased at the beginning of the Build-up period. Figure 4 illustrates permissible warm capital purchase patterns.

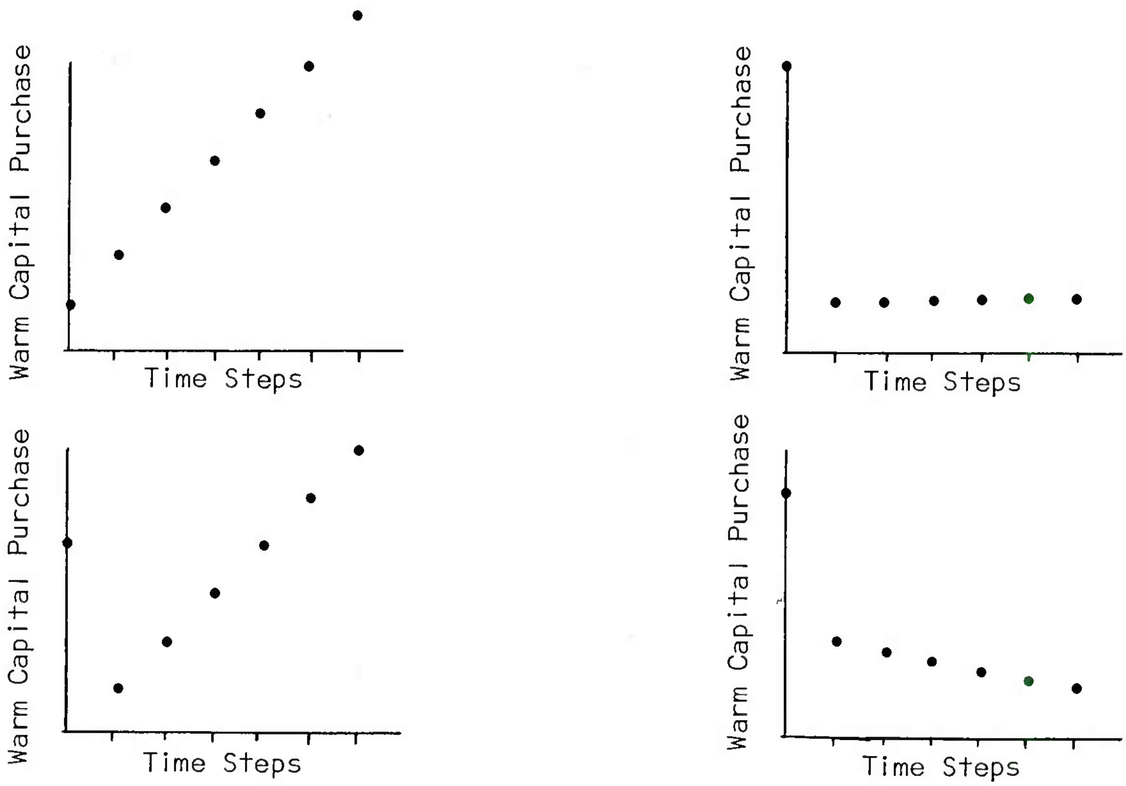

Figure 4. ALLOWABLE WARM CAPITAL PURCHASES

The model variables that determine this family of purchase patterns are:

BW1 = the amount of type 1 warm capital purchased during time step 1 as part of the linear portion of the purchase pattern

BW2 = the amount of type 2 warm capital purchased during time step 1 as part of the linear portion of the purchase pattern

IBW1 = the amount of type 1 warm capital purchased during time step 1 in addition to BW1

IBW2 = the amount of type 2 warm capital purchased during time step 1 in addition to BW2

SLPPW1 = the positive component of the slope of the linear portion of the type 1 warm capital purchase pattern

SLPNW1 = the negative component of the slope of the linear portion of the type 1 warm capital purchase pattern

SLPPW2 = the positive component of the slope of the linear portion of the type 2 warm capital purchase pattern

SLPNW2 = the negative component of the slope of the linear portion of the type 2 warm capital purchase pattern.

Therefore, at time step t = 1, the amounts of types 1 and 2 warm capital purchased are, respectively

$$BW1 + IBW1$$

and

$$BW2 + IBW2$$

while for time steps t between t = 2 and t = NPURCH, the amounts of warm capital purchased are

$$BW1 + (t-1) \cdot (SLPPW1-SLPNW1)$$

and

$$BW2 + (t-1) \cdot (SLPPW2-SLPNW2).$$

The amounts of warm capital at the end of the Build-up period are given by expressions similar to those for cold capital. The only differences are the IBW1 and IBW2 terms which can clearly be handled the same way as original warm capital. Let

OWARM1 = the amount of original type 1 warm capital, and

OWARM2 = the amount of original type 2 warm capital.

Then the amounts of type 1 and type 2 warm capital at the end of the Build-up period are given by the following expressions:

$$(12) \quad BW1 \cdot \left[\sum_{i=1}^{NPURCH} (1-DW1)^{i-1}\right] + (SLPPW1-SLPNW1) \cdot \left[\sum_{i=1}^{NPURCH-1} i(1-DW1)^{NPURCH-1-i}\right]$$

$$+ (IBW1 + OWARM1) \cdot (1-DW1)^{NPURCH-1}$$

$$(13) \quad BW2 \cdot \left[\sum_{i=1}^{NPURCH} (1-DW2)^{i-1}\right] + (SLPPW2-SLPNW2) \cdot \left[\sum_{i=1}^{NPURCH-1} i(1-DW2)^{NPURCH-1-i}\right]$$

$$+ (IBW2 + OWARM2) \cdot (1-DW2)^{NPURCH-1} .$$

As warm capital is purchased, ammunition is produced. Some of this ammunition goes to satisfy peacetime demand, another portion is lost to deterioration. The ammunition remaining at the end of the Build-up period can be determined using much the same approach illustrated by Table 1, with the inclusion of ammunition production and deterioration, and the satisfaction of ammunition demands. If

OMUN = the amount of original ammunition,

BPDEM = the demand for ammunition during each time step of the Build-up period,

then the size of the ammunition stockpile at the end of the Build-up period is

$$(14) \quad \frac{BW1}{KW1} \cdot \left[\sum_{j=1}^{NPURCH} (1-DS)^{NPURCH-j} \cdot \left\{\sum_{i=1}^{j} (1-DW1)^{i-1}\right\}\right]$$

$$+ \frac{BW2}{KW2} \cdot \left[\sum_{j=1}^{NPURCH} (1-DS)^{NPURCH-j} \cdot \left\{\sum_{i=1}^{j} (1-DW2)^{i-1}\right\}\right]$$

$$+ \frac{(SLPPW1-SLPNW1)}{KW1} \cdot \left[\sum_{j=1}^{NPURCH} (1-DS)^{NPURCH-j} \cdot \left\{\sum_{i=1}^{j-1} i(1-DW1)^{j-1-i}\right\}\right]$$

$$+ \frac{(SLPPW2-SLPNW2)}{KW1} \cdot \left[\sum_{j=1}^{NPURCH} (1-DS)^{NPURCH-j} \cdot \left\{\sum_{i=1}^{j-1} i(1-DW2)^{j-1-i}\right\}\right]$$

(continued on next page)

$$+ \frac{(IBW1+OWARM1)}{KW1} \cdot \left[\sum_{i=1}^{NPURCH-1} (1-DW1)^{NPURCH-1-i} \cdot (1-DS)^{i} \right]$$

$$+ \frac{(IBW2+OWARM2)}{KW2} \cdot \left[\sum_{i=1}^{NPURCH-1} (1-DW2)^{NPURCH-1-i} \cdot (1-DS)^{i} \right]$$

$$- BPDEM \cdot \left[\sum_{j=1}^{NPURCH-1} (1-DS)^{j-1} \right] + OMUN \cdot (1-DS)^{NPURCH-1} .$$

Note: In the above expression, and throughout this paper, we will adopt the convention that in summation of the form $\sum_{i=a}^{b} f(i)$, where $b < a$, is equal to zero.

c. <u>Feasibility Consideration</u>

Certain constraints are imposed on these variables to ensure that the purchase patterns are feasible. In particular, we demand that the amounts of capital purchased during any time step of the Build-up period are nonnegative. This can be ensured by the nonnegativity of the model variables and by the following constraints:

(15) $$BC1 + (NPURCH-1) \cdot (SLPPC1-SLPNC1) \geq 0$$

(16) $$BC2 + (NPURCH-1) \cdot (SLPPC2-SLPNC2) \geq 0$$

(17) $$BW1 + (NPURCH-1) \cdot (SLPPW1-SLPNW1) \geq 0$$

(18) $$BW2 + (NPURCH-1) \cdot (SLPPW2-SLPNW2) \geq 0 .$$

We also require that the warm capital purchased also be able to satisfy Build-up period demand for ammunition. This will generally be ensured by requiring that production be sufficient to satisfy this demand at both the beginning and end of the Build-up period. These constraints take the form

(19) $\frac{1}{KW1}(IBW1+BW1+OWARM1) + \frac{1}{KW2}(IBW2+BW2+OWARM2) \geq BPDEM$

(20) $$\frac{1}{KW1} \cdot \langle 12 \rangle + \frac{1}{KW2} \cdot \langle 13 \rangle \geq BPDEM$$

where ⟨12⟩ stands for expression (12) above and ⟨13⟩ stands for expression (13).

d. Costs

In this section we list the costs associated with each variable of the Build-up period. Because we have compressed the core model variables into the fewer Build-up period variables of the S/PB model, each variable will have associated with it two or more costs from the core model.

BC1

Two costs are associated with BC1. The first accounts for the actual purchase of type 1 capital and the second specifies the costs of maintaining that capital, taking into account the fact that some of that capital is deteriorating.

The unit purchase costs over the Build-up period are simply

(21) $$VPC1 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i-LP1}} .$$

This is because, during each time step t, the costs of purchasing capital through this variable are just

$$BC1 \cdot VPC1/(1+R)^{t-LP1} .$$

This expression implies that we discount costs beginning with time step t = 1, a convention we will maintain throughout this

paper. Note that we have corrected the costs for the time lag LP1 connected with the purchase of type 1 capital.

The second cost is that associated with maintaining the cold capital stocks contributed by BC1. Table 2 lists the cold stock level, over time, contributed by the BC1, taking deterioration into account.

Table 2. COLD STOCKS CONTRIBUTED BY BC1

Time Step	Stock Level
1	$BC1$
2	$BC1 \cdot (1-DC1)BC1$
3	$BC1 + (1-DC1)BC1 + (1-DC1)^2 \cdot BC1$
.	.
.	.
.	.
NPURCH	$BC1 \left[\sum_{i=1}^{NPURCH} (1-DC1)^{i-1} \right]$

Therefore the unit cost of maintaining the portion of the type 1 cold stock contributed by BC1 is

$$(22) \qquad VC1 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^i} \cdot \left[\sum_{j=1}^{i} (1-DC1)^{j-1} \right]$$

so that the total unit cost associated with BC1 is

$$(23) \qquad \langle 21 \rangle + \langle 22 \rangle \quad ;$$

that is, the total cost attributable to BC1 is

$$BC1 \cdot \langle 23 \rangle \quad .$$

BC2

The unit cost of BC2 can be calculated in precisely the same manner as those of BC1. The result is

$$(24) \quad VPC2 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1-R)^{i-LP2}} + VC2 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}}\left[\sum_{j=1}^{i} (1-DC2)^{j-1}\right].$$

SLPPC1-SLPNC1

The costs associated with the quantity (SLPPC1-SLPNC1) also comprise purchase and stockpile maintenance costs. It is not difficult to see that the unit purchase costs are

$$(25) \qquad VPC1 \cdot \sum_{i=1}^{NPURCH} \frac{i-1}{(1+R)^{i-LP1}} \quad .$$

To determine the stockpile maintenance cost contributed by (SLPPC1-SLPNC1), consider Table 3. Note that if the difference (SLPPC1-SLPNC1) is negative, the stock levels contributed are negative, which is perfectly reasonable, since these are only part of the total stocks.

Table 3. COLD STOCKS CONTRIBUTED BY (SLPPC1-SLPNC1)

Time Step	Stock Level
1	0
2	SLPPC1 - SLPNC1
3	2(SLPPC1-SLPNC1) + (1-DC1)(SLPPC1-SLPNC1)
.	.
.	.
.	.
NPURCH	$(SLPPC1-SLPNC1)\left[\sum_{i=1}^{NPURCH-1} i(1-DC1)^{NPURCH-1-i}\right]$

Therefore, the unit stockpile maintenance costs are

$$(26) \qquad VC1 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \cdot \left[\sum_{j=1}^{i-1} j(1-DC1)^{i-1-j} \right]$$

so that the total unit cost associated with (SLPPC1-SLPNC1) is

$$(27) \qquad \langle 25 \rangle + \langle 26 \rangle \quad .$$

SLPPC2-SLPNC2

An analysis similar to the one above shows the unit cost associated with (SLPPC2-SLPNC2) to be

$$(28) \qquad VPC2 \cdot \sum_{i=1}^{NPURCH} \frac{i-1}{(1+R)^{i-LP2}} +$$

$$VC2 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(i+R)^{i}} \cdot \left[\sum_{j=1}^{i-1} j(1-DC2)^{i-1-j} \right] \quad .$$

IBW1

The variables describing warm capital purchases are associated with the following costs.

(1) The cost of purchasing the capital

(2) The cost of transferring capital from cold to warm stocks

(3) The cost of maintaining the warm stocks

(4) The costs of ammunition production

(5) The costs of maintaining the ammunition stockpile.

To determine the costs contributed by IBW1, first consider Table 4. The unit purchase cost associated with IBW1 is clearly

Table 4. RESOURCES CONTRIBUTED BY IBW1

Time Step	Warm Stocks Contributed by IBW1	Ammunition Production Contributed by IBW1	Ammunition Stockpile Contributed by IBW1
1	$IBW1$	$\frac{IBW1}{KW1}$	$\frac{IBW1}{KW1}$
2	$IBW1 \cdot (1-DW1)$	$\frac{IBW1}{KW1} \cdot (1-DW1)$	$\frac{IBW1}{KW1} \cdot (1-DW1) + \frac{IBW1}{KW1} \cdot (1-DS)$
3	$IBW1 \cdot (1-DW1)^2$	$\frac{IBW1}{KW1} \cdot (1-DW1)^2$	$\frac{IBW1}{KW1} \cdot (1-DW1)^2 + \frac{IBW1}{KW1} \cdot (1-DW1)(1-DS) + \frac{IBW1}{KW1}(1-DS)^2$
$\vdots$	$\vdots$	$\vdots$	$\vdots$
NPURCH	$IBW1 \cdot (1-DW1)^{NPURCH-1}$	$\frac{IBW1}{KW1} \cdot (1-DW1)^{NPURCH-1}$	$\frac{IBW1}{KW1} \sum_{i=1}^{NPURCH-1} (1-DS)^i (1-DW1)^{NPURCH-1-i}$

$$(29) \qquad VPC1 \cdot \frac{1}{(1+R)^{1-LCW1-LP1}} \quad .$$

Note that the time required to transfer the capital to warm stocks has been factored into the discount coefficient.

The unit cost of the cold to warm transfer is

$$(30) \qquad VCW1 \cdot \frac{1}{(1+R)^{1-LCW1}} \quad .$$

The warm stockpile maintenance unit cost can be determined from Table 4 to be

$$(31) \qquad VW1 \cdot \sum_{i=1}^{NPURCH} \frac{(1-DW1)^{i-1}}{(1+R)^{i}} \quad .$$

The cost per unit of ammunition production contributed by IBW1 is given by

$$(32) \qquad \frac{VPW1}{KW1} \cdot \sum_{i=1}^{NPURCH} \frac{(1-DW1)^{i-1}}{(1+R)^{i}} \quad .$$

Finally, the unit cost of maintaining the component of warm stocks contributed by IBW1 is

$$(33) \qquad \frac{VS}{KW1} \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \cdot \left[\sum_{j=1}^{i-1} (1-DW1)^{j} (1-DS)^{i-1-j} \right] \quad .$$

The sum of these

$$(34) \qquad \langle 29 \rangle + \langle 30 \rangle + \langle 31 \rangle + \langle 32 \rangle + \langle 33 \rangle$$

constitutes the total unit cost associated with IBW1.

IBW2

The same logic yields the unit cost associated with IBW2:

$$(35)\quad \frac{VPC2}{(1+R)^{1-LCW2-LP2}} + \frac{VCW2}{(1+R)^{1-LCW2}} + VW2 \cdot \sum_{i=1}^{NPURCH} \frac{(1-DW2)^{i-1}}{(1+R)^{i}}$$

$$+ \frac{VPW2}{KW2} \cdot \sum_{i=1}^{NPURCH} \frac{(1-DW2)^{i-1}}{(1+R)^{i}}$$

$$+ \frac{VS}{KW2} \cdot \sum_{i=1}^{NPURCH} \frac{1}{(i+R)^{i}} \cdot \left[\sum_{j=1}^{i-1} (1-DW2)^{j}(1-DS)^{i-1-j}\right] .$$

BW1

Consider the contributions by BW1 listed in Table 5. Certainly, the unit purchase cost is

$$(36)\qquad VPC1 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i-LCW1-LP1}}$$

and the unit transfer cost is

$$(37)\qquad VCW1 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i-LCW1}} .$$

From Table 5, one can determine the unit stock maintenance to be

$$(38)\qquad VW1 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \cdot \left[\sum_{j=1}^{i} (1-DW1)^{j-1}\right]$$

and the unit ammunition production cost is

Table 5. RESOURCES CONTRIBUTED BY BW1

Time Step	Warm Stocks Contributed by BW1	Ammunition Production Contributed by BW1	Ammunition Stockpile Contributed by BW1
1	BW1	$\frac{BW1}{KW1}$	$\frac{BW1}{KW1}$
2	$BW1 + (1-DW1)\cdot BW1$	$\frac{BW1}{KW1} \cdot [1+(1-DW1)]$	$\frac{BW1}{KW1} \cdot [1+(1-DW1)]+\frac{BW1}{KW1}\cdot(1-DS)$
3	$BW1 + (1-DW1)\cdot BW1 + (1-DW1)^2 . BW1$	$\frac{BW1}{KW1} \cdot [1+(1-DW1)+(1-DW1)^2]$	$\frac{BW1}{KW1}[1+(1-DW1)+(1-DW1)^2]+\frac{BW1}{KW1}[1+(1-DW1)](1-DS)+\frac{BW1}{KW1}(1-DS)^2$
. . .	. . .	. . .	. . .
NPURCH	$BW1 \cdot \left[\sum_{i=1}^{NPURCH} (1-DW1)^{i-1}\right]$	$\frac{BW1}{KW1} \cdot \left[\sum_{i=1}^{NPURCH} (1-DW1)^{i-1}\right]$	$\frac{BW1}{KW1} \sum_{i=1}^{NPURCH} (1-DS)^{NPURCH-i} \left[\sum_{j=1}^{i} (1-DW1)^{j-1}\right]$

(39) $$\frac{VPW1}{KW1} \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \cdot \left[\sum_{j=1}^{i} (1-DW1)^{j-1} \right] .$$

Finally, the unit stockpile maintenance cost associated with BW1 is

(40) $$\frac{VS}{KW1} \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \cdot \sum_{j=1}^{i} (1-DS)^{i-j} \cdot \left[\sum_{k=1}^{j} (1-DW1)^{k-1} \right] .$$

Thus the total unit cost of BW1 is

(41) $$\langle 36 \rangle + \langle 37 \rangle + \langle 38 \rangle + \langle 39 \rangle + \langle 40 \rangle .$$

BW2

The unit cost associated with BW2 is

(42) $$VPC2 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i-LCW2-LP2}} + VCW2 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i-LCW2}}$$

$$+ VW2 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \left[\sum_{j=1}^{i} (1-DW2)^{j-1} \right]$$

$$+ \frac{VPW2}{KW2} \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \left[\sum_{j=1}^{i} (1-DW2)^{j-1} \right]$$

$$+ \frac{VS}{KW2} \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \sum_{j=1}^{i} (1-DS)^{i-j} \left[\sum_{k=1}^{j} (1-DW2)^{k-1} \right] .$$

SLPPW1-SLPNW1

Table 6 gives the progression of resources contributed over time by the difference (SLPPW1-SLPNW1).

The unit purchase cost is simply

Table 6. RESOURCES CONTRIBUTED BY (SLPPW1-SLPNW1)

Time Step	Warm Stocks Contributed by S = (SLPPW1-SLPNW1)	Ammunition Production Contributed by S = (SLPPW1-SLPNW1)	Ammunition Stockpile Contributed by S = (SLPPW1-SLPNW1)
1	0	0	0
2	S	$\frac{S}{KW1}$	$\frac{S}{KW1}$
3	2S + S(1-DW1)	$\frac{2S+S(1-DW1)}{KW1}$	$\frac{2S+S(1-DW1)}{KW1} + \frac{S}{KW1}(1-DS)$
. . .	. . .	. . .	. . .
NPURCH	$S \sum_{i=1}^{NPURCH-1} i(1-DW1)^{NPURCH-1-i}$	$\frac{S}{KW1} \sum_{i=1}^{NPURCH-1} i(1-DW1)^{NPURCH-1-i}$	$\frac{S}{KW1} \sum_{i=1}^{NPURCH} (1-DS)^{NPURCH-i} \sum_{j=1}^{i-1} j(1-DW1)^{i-1-j}$

$$(43) \qquad VPC1 \cdot \sum_{i=1}^{NPURCH} \frac{i-1}{(1+R)^{i-LCW1-LP1}}$$

and the unit transfer cost is similarly

$$(44) \qquad VCW1 \cdot \sum_{i=1}^{NPURCH} \frac{i-1}{(1+R)^{i-LCW1}} \ .$$

From Table 6, one can determine the unit stockpile maintenance cost to be

$$(45) \qquad VW1 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \cdot \sum_{j=1}^{i-1} j(1-DW1)^{i-1-j}$$

while the unit ammunition production cost is

$$(46) \qquad \frac{VPW1}{KW1} \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \cdot \sum_{j=1}^{i-1} j(1-DW1)^{i-1-j} \ .$$

Lastly, the unit ammunition stockpile maintenance cost contributed by (SLPPW1-SLPNW1) is

$$(47) \quad \frac{VS}{KW1} \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \cdot \sum_{j=1}^{i} (1-DS)^{i-j} \cdot \sum_{k=1}^{j-1} k(1-DW1)^{j-1-k}$$

The total unit cost associated with (SLPPW1-SLPNW1) is therefore

$$(48) \qquad \langle 43\rangle + \langle 44\rangle + \langle 45\rangle + \langle 46\rangle + \langle 47\rangle \ .$$

SLPPW2 - SLPNW2

Finally, the total unit cost associated with (SLPPW2-SLPNW2) is

$$(49) \qquad VPC2 \cdot \sum_{i=1}^{NPURCH} \frac{i-1}{(1+R)^{i-LCW2-LP2}} + VCW2 \cdot \sum_{i=1}^{NPURCH} \frac{i-1}{(1+R)^{i-LCW2}}$$

$$+ VW2 \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \cdot \sum_{j=1}^{i-1} j(1-DW2)^{i-1-j}$$

$$+ \frac{VPW2}{KW2} \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \cdot \sum_{j=1}^{i-1} j(1-DW2)^{i-1-j}$$

$$+ \frac{VS}{KW2} \cdot \sum_{i=1}^{NPURCH} \frac{1}{(1+R)^{i}} \cdot \sum_{j=1}^{i} (1-DS)^{i-j} \cdot \sum_{k=1}^{j-1} k(1-DW2)^{j-1-k} \quad .$$

It should be noted that there are additional costs associated with the Build-up period that do not depend on the variable values. These are the costs of maintaining the original cold and warm capital stocks, the costs of ammunition production by the original warm stocks, and the cost of maintaining the original ammunition stockpile as well as that produced by original warm capital. There are also savings to be considered because ammunition that goes to satisfy demand during this period need not be maintained. These costs and savings, however, are fixed. They depend only on original resource levels and on the demand for ammunition during the Build-up period; therefore, they are explicitly excluded from the objective function of the S/PB model.

e. Time Delay in Capital Acquisition

So far we have described the Build-up period as if there were no time delay in acquiring capital. For most problems

there will be some time delay which we denote by NLAG and explicitly define as the initial time delay from the decision to buy new capital to the time it can first produce. This delay may be different from the time delay for acquiring capital during the Mobilization/War period which will be discussed later. The general effect of the NLAG delay on the model is that during the first NLAG periods of the Build-up period new capital is not yet available, stocks are being produced by the initial warm capital and consumed, and costs are accruing due to production and maintenance. The important thing to realize is that these factors are not affected by anything over which we have a choice and thus are not part of the mathematical programming model itself. The results of the decision to buy new capital are not felt until time period NLAG+1, when new capital first arrives. The NLAG period does affect the mathematical programming model indirectly by determining the amount of capital and stocks at time NLAG+1. The amount of stocks at the end of NLAG periods is given by Equation (14) with all variables relating to capital buys set to zero.

2. The Steady-State Period

At the end of the Build-up period, we enter the Steady-state period, in which the chief actions taken are those required to maintain the capital and ammunition determined during the Build-up period. The basic unit of time is the time step, and the Steady-state period is assumed to be NSS time steps long. NSS is allowed to be zero, by which the user indicates that the scenario moves directly from the Build-up period to the Mobilization/War period.

a. Steady-State Variables and Equations

As before, we assume that the demand for ammunition during this period is constant over time, that no hot capital appears,

that time lags appear only in the costs, and that the domestic and in-theater ammunition stockpiles are essentially indistinguishable.

Among the variables of this period are

ES = the total amount of ammunition held in stockpiles during this period

EC1 = the amount of type 1 cold capital held during this period

EC2 = the amount of type 2 cold capital held during this period

EW1 = the amount of type 1 warm capital held during this period

EW2 = the amount of type 2 warm capital held during this period.

An equation that must obviously hold is

$$\text{ES} = \langle 14 \rangle \quad ; \tag{50}$$

that is, the ammunition held during this period is equal to that acquired during the Build-up period. In order for this to be constant over the period, it must be true that

$$\frac{\text{EW1}}{\text{KW1}} + \frac{\text{EW2}}{\text{KW2}} = \text{SSDEM} + \text{ES} \cdot \text{DS} \tag{51}$$

where

SSDEM = the demand for ammunition per time step during the Steady-state period.

Equation (51) is a statement that the total production, per time step, is precisely that necessary to meet demand and to replace the ammunition that has deteriorated during each previous time step. In case NSS = 0, there will be no demand or deterioration and this equation will not appear in the model.

Because this period is a peacetime period, we must ensure that the amount of warm capital acquired during the Build-up period is sufficient to maintain the stockpile level. Therefore, when NSS > 0, we require that

(52) $$EW1 \leq \langle 12 \rangle$$

and

(53) $$EW2 \leq \langle 13 \rangle \ .$$

Note that this implies that cold capital acquired during the Build-up period is acquired solely for the needs of the Mobilization/War period. In other words, the preparation during the Build-up period must take the Steady-state period into account.

When NSS = 0, we replace (52) and (53) by

(54) $$EW1 = \langle 12 \rangle$$

(55) $$EW2 = \langle 13 \rangle$$

in order to tie together the Build-up and the Mobilization/War periods.

In general, more capital will be in warm stocks at the end of the Build-up period than will be required during the Steady-state period. The excess warm stocks are put into cold stocks for future use:

(56) $$EC1 + EW1 = \langle 10 \rangle + \langle 12 \rangle$$

(57) $$EC2 + EW2 = \langle 11 \rangle + \langle 13 \rangle \ .$$

To permit the model to enter the Mobilization/War period with distinct domestic and in-theater ammunition stockpiles, we perform, during this period, what we shall call the <u>prepositioning</u> of ammunition through the use of the following variable.

EPREP = the amount of ammunition explicitly prepositioned into the in-theater stockpile during the Steady-state period.

The only structural constraint on this prepositioning is

(58) $$EPREP \leq ES \ ;$$

that is, one cannot preposition more ammunition than one has.

The amount of ammunition remaining in the domestic stockpile is then

(59) $$\mathrm{ES} - \mathrm{EPREP}.$$

b. Costs

The costs of this period include those of explicit activities, such as ammunition production, as well as those of implicit activities, such as the purchase of capital to replace that which deteriorates. The unit costs associated with each variable of the Steady-state period are as follows.

EC1

The maintenance cost of one unit of EC1 throughout the Steady-state period is clearly

(60) $$\mathrm{VC1} \cdot \sum_{i=1}^{\mathrm{NSS}} \frac{1}{(1+R)^{i+\mathrm{NPURCH}}} .$$

The NPURCH term in the exponent of the denominator represents the fact that the first time step of the Steady-state period is time step t = NPURCH + 1.

Because type 1 cold capital deteriorates by an amount EC1 · DC1 during each time step, we must include the cost of purchasing capital to maintain the type 1 cold capital stocks at an even level. This cost, per unit of EC1, is

(61) $$\mathrm{VPC1} \cdot \mathrm{DC1} \cdot \sum_{i=1}^{\mathrm{NSS}} \frac{1}{(1+R)^{i-\mathrm{LP1}+\mathrm{NPURCH}}} ,$$

so that the total unit cost associated with EC1 is

(62) $$\langle 60 \rangle + \langle 61 \rangle .$$

EC2

In a like manner, the unit cost of EC2 is

$$(63)\quad \left(VC2 \cdot \sum_{i=1}^{NSS} \frac{1}{(1+R)^{i+NPURCH}}\right)+\left(VPC2 \cdot DC2 \cdot \sum_{i=1}^{NSS} \frac{1}{(1+R)^{i-LP2+NPURCH}}\right).$$

EW1

The cost associated with Steady-state warm capital comprises

(1) the purchase of replacement capital to correct deterioration

(2) the cost of transferring that capital to warm stocks

(3) the cost of maintaining the warm stocks, and

(4) the cost of producing ammunition.

In order, these unit costs are, for type 1 capital

$$(63)\quad VPC1 \cdot DW1 \cdot \sum_{i=1}^{NSS} \frac{1}{(1+R)^{i-LCW1-LP1+NPURCH}}$$

$$(64)\quad VCW1 \cdot DW1 \cdot \sum_{i=1}^{NSS} \frac{1}{(1+R)^{i-LCW1+NPURCH}}$$

$$(65)\quad VW1 \cdot \sum_{i=1}^{NSS} \frac{1}{(1+R)^{i+NPURCH}}$$

$$(66)\quad \frac{VPW1}{KW1} \cdot \sum_{i=1}^{NSS} \frac{1}{(1+R)^{i+NPURCH}} .$$

The total unit cost of EW1 is then

$$(67)\quad \langle 63\rangle + \langle 64\rangle + \langle 65\rangle + \langle 66\rangle .$$

EW2

The total unit cost for type 2 warm capital during the Steady-state period is

$$(68) \quad VPC2 \cdot DW2 \cdot \sum_{i=1}^{NSS} \frac{1}{(1+R)^{i-LCW2-LP2+NPURCH}}$$

$$+ VCW2 \cdot DW2 \cdot \sum_{i=1}^{NSS} \frac{1}{(1+R)^{i-LCW2+NPURCH}}$$

$$+ VW2 \cdot \sum_{i=1}^{NSS} \frac{1}{(1+R)^{i+NPURCH}}$$

$$+ \frac{VPW2}{KW2} \cdot \sum_{i=1}^{NSS} \frac{1}{(1+R)^{i+NPURCH}} \quad .$$

ES

The cost of maintaining the Steady-state stockpile, per unit, is

$$(69) \qquad VS \cdot \sum_{i=1}^{NSS} \frac{1}{(1+R)^{i+NPURCH}} \quad .$$

EPREP

We assume, for costing purposes, that the prepositioned stocks are separated from the ammunition stockpile during the last time step of the Steady-state period. The user must assess this one-time cost and supply it as the parameter VPREP which is then discounted. The unit cost associated with the variable EPREP is therefore

$$(70) \qquad VPREP \cdot \frac{1}{(1+R)^{NSS+NPURCH}} \quad .$$

3. Mobilization/War Period

The Mobilization/War period, which is assumed to last ISTEP time steps, follows the Steady-state period, except when NSS = 0, which places the Mobilization/War period directly after the Build-up period (although the Steady-state variables still appear in the model).

The structural equations of this period closely resemble the core model--this period is explicitly time stepped--except that those pertaining to the earlier time steps of this period are modified to provide the interface with the previous two periods. In particular, stock and stockpile levels at the start of this period must reflect the levels at the end of the Steady-state period and also the transfer variables in the initial stages of this period must be set to appropriate values. As with the core model, each of the following equations represents a sequence of equations as t ranges from 1 to ISTEP.

a. Cold Capital Stocks

(71) $$C1(t) = \langle a \rangle \cdot (1-DC1) + \langle b \rangle + \langle c \rangle + \langle d \rangle - TCH1(t) - TCW1(t)$$

where

$$\langle a \rangle = \begin{cases} EC1 & \text{if } t = 1 \\ C1(t-1) & \text{if } t \geq 2 \end{cases}$$

$$\langle b \rangle = \begin{cases} EC1 \cdot DC1 + EW1 \cdot DW1 & \text{if } 1 - NSS \leq t - LP1 \leq 0 \\ PC1(t-LP1) & \text{if } t - LP1 \geq 1 \\ 0 & \text{if } t - LP1 < 1 - NSS \end{cases}$$

$$\langle c \rangle = \begin{cases} TWC1(t-LWC1) & \text{if } t - LWC1 \geq 1 \\ 0 & \text{if } t - LWC1 \leq 0 \end{cases}$$

$$\langle d \rangle = \begin{cases} \text{THC1}(t-\text{LHC1}) & \text{if } t - \text{LHC1} \geq 1 \\ 0 & \text{if } t - \text{LHC1} \leq 0 \,. \end{cases}$$

The expressions $\langle a \rangle$, $\langle b \rangle$, $\langle c \rangle$, and $\langle d \rangle$ constitute the interface between the type 1 cold capital equations of the Mobilization/War period and the previous periods. These terms reflect both the explicit activities of these periods as well as implicit ones.

Expression $\langle a \rangle$ brings the type 1 cold capital accrued during the first two periods into the Mobilization/War period. For time steps $t \geq 2$, this term reflects the cold capital of the previous time step, which is then adjusted for deterioration. However, when t=1, the previous type 1 cold capital is that in the Steady-state period and hence $\langle a \rangle$ is set to EC1.

Expression $\langle b \rangle$ reflects purchases of type 1 capital. When $t - \text{LP1} \geq 1$, these purchases are those that have been generated earlier in the Mobilization/War period which are only presently entering cold stocks. If $t - \text{LP1} < 1 - \text{NSS}$, then the time lag combined with the time step is such that the purchases entering cold stocks at this time step t would have had to have been purchased during the Build-up period. We have assumed, however, that purchases during that period entered cold stocks immediately and hence have already been accounted for. Therefore, we set $\langle b \rangle = 0$. For $1 - \text{NSS} \leq t - \text{LP1} \leq 0$, the purchases are those that would have had to be purchased during the Steady-state period. Recall that Steady-state purchases are implicit activities; that is, their costs are accounted for but there is no Steady-state variable corresponding to purchases of capital. Rather, we have assumed that the purchases during the Steady-state period are precisely what is needed to maintain capital stock levels. This is clearly $\text{EC1} \cdot \text{DC1} + \text{EW1} \cdot \text{DW1}$ units of capital per time step, which we allow to be brought forward into the Mobilization/War period. In this way continuity

is provided between the Steady-state and Mobilization/War periods.

Expression $\langle c \rangle$ represents warm to cold transfer of type 1 capital. Because we have assumed that the only such transfer prior to the Mobilization/War period is that at the end of the Build-up period, which has already been explicitly included in the values of the Steady-state variables, for all time steps t for which $t - LCW1 \leq 0$, we set $\langle c \rangle = 0$. For those values of t for which $t - LCW1 \geq 1$, this transfer occurs entirely within the Mobilization/War period and so $\langle c \rangle = TWC1(t-LWC1)$.

Expression $\langle d \rangle$ stands for hot to cold transfer of type 1 capital. Because we have assumed that there is no hot capital prior to the Mobilization/War period, $\langle d \rangle$ must clearly equal 0 if $t - LHC1 \leq 0$. For all other time steps t, $\langle d \rangle = THC1(t-LHC1)$.

For type 2 cold stocks, the representative equation is

$$C2(t) = \langle a \rangle \cdot (1-DC2) + \langle b \rangle + \langle c \rangle + \langle d \rangle - TCH2(t) - TCW2(t) \tag{72}$$

where

$$\langle a \rangle = \begin{cases} EC2 & \text{if } t = 1 \\ C2(t-1) & \text{if } t \geq 2 \end{cases}$$

$$\langle b \rangle = \begin{cases} EC2 \cdot DC2 + EW2 \cdot DW2 & \text{if } 1 - NSS \leq t - LP2 \leq 0 \\ PC2(t-LP2) & \text{if } t - LP2 \geq 1 \\ 0 & \text{if } t - LP2 < 1 - NSS \end{cases}$$

$$\langle c \rangle = \begin{cases} TWC2(t-LWC2) & \text{if } t - LWC2 \geq 1 \\ 0 & \text{if } t - LWC2 \leq 0 \end{cases}$$

$$\langle d \rangle = \begin{cases} THC2(t-LHC2) & \text{if } t - LHC2 \geq 1 \\ 0 & \text{if } t - LHC2 \leq 0 \end{cases}$$

b. <u>Warm Capital Stocks</u>

For type 1 warm capital stocks, the appropriate equation is

(73) $$W1(t) = \langle a \rangle \cdot (1-DW1) + \langle b \rangle + \langle c \rangle - TWC1(t) - TWH1(t)$$

where

$$\langle a \rangle = \begin{cases} EW1 & \text{if } t = 1 \\ W1(t-1) & \text{if } t \geq 2 \end{cases}$$

$$\langle b \rangle = \begin{cases} DW1 \cdot EW1 & \text{if } 1 - NSS \leq t - LCW1 \leq 0 \\ TCW1(t-LCW1) & \text{if } t - LCW1 \geq 1 \\ 0 & \text{if } t - LCW1 < 1 - NSS \end{cases}$$

$$\langle c \rangle = \begin{cases} THW1(t-LHW1) & \text{if } t - LHW1 \geq 1 \\ 0 & \text{if } t - LHW1 \leq 0 \end{cases}$$

The expression $\langle a \rangle$ brings the Steady-state type 1 warm capital into the Mobilization/War period during time step t=1. For later time steps, $\langle a \rangle$ represents the carry-over of the previous time step's warm capital.

Expression $\langle b \rangle$ stands for cold to warm capital transfer. If $t - LCW1 \geq 1$, then the entire transfer occurs during the Mobilization/War period and $\langle b \rangle = TCW1(t-LCW1)$. If $t - LCW1 < 1 - NSS$, the transfer would have had to originate in the Build-up period, during which, we have assumed, there are no such transfers. Therefore, in this case, $\langle b \rangle = 0$. If $1 - NSS \leq t - LCW1 \leq 0$, we set $\langle b \rangle$ equal to the implicit cold to warm transfer during the Steady-state period which is the $EW1 \cdot DW1$ units per time step that were needed to correct for deterioration.

Expression $\langle c \rangle$ represents hot to warm capital transfer. Prior to the Mobilization/War period, there are no hot capital stocks and so $\langle c \rangle = 0$ if $t - LHW1 \leq 0$. Otherwise, $\langle c \rangle = THW1(t-LHW1)$.

Type 2 warm capital stocks are described by Equation (74).

$$(74) \qquad W2(t) = \langle a \rangle \cdot (1-DW2) + \langle b \rangle + \langle c \rangle - TWC2(t) - TWH2(t)$$

where

$$\langle a \rangle = \begin{cases} EW2 & \text{if } t = 1 \\ W2(t-1) & \text{if } t \geq 2 \end{cases}$$

$$\langle b \rangle = \begin{cases} DW2 \cdot EW2 & \text{if } 1 - NSS \leq t - LCW2 \leq 0 \\ TCW2(t-LCW2) & \text{if } t - LCW2 \geq 1 \\ 0 & \text{if } t - LCW2 < 1 - NSS \end{cases}$$

$$\langle c \rangle = \begin{cases} THW2(t-LHW2) & \text{if } t - LHW2 \geq 1 \\ 0 & \text{if } t - LHW1 \leq 0 \end{cases}$$

c. Hot Capital Stocks

The type 1 hot capital stocks are modelled by the following equation:

$$(75) \qquad H1(t) = \langle a \rangle \cdot (1-DH1) + \langle b \rangle + \langle c \rangle - THC1(t) - THW1(t)$$

where

$$\langle a \rangle = \begin{cases} H1(t-1) & \text{if } t \geq 2 \\ 0 & \text{if } t = 1 \end{cases}$$

$$\langle b \rangle = \begin{cases} TCH1(t-LCH1) & \text{if } t - LCH1 \geq 1 \\ 0 & \text{if } t - LCH1 \leq 0 \end{cases}$$

$$\langle c \rangle = \begin{cases} TWH1(t-LWH1) & \text{if } t - LWH1 \geq 1 \\ 0 & \text{if } t - LWH1 \leq 0 \end{cases}$$

Expression $\langle a \rangle$, the hot capital carry-over, must clearly be zero when t=1. For $t \geq 2$, $\langle a \rangle$ is simply H1(t-1). Expressions $\langle b \rangle$ and $\langle c \rangle$ represent, respectively, the type 1 cold-to-hot and warm-to-hot capital transfers. Because there is no hot

capital prior to the Mobilization/War period, we permit no transfers to hot capital to originate during previous periods. Therefore, these are zero when t - LCH1 and t - LWH1, respectively, are less than or equal to zero. Otherwise $\langle b \rangle = TCH1(t-LCH1)$ and $\langle c \rangle = TWH1(t-LWH1)$.

The corresponding equation for type 2 hot capital is:

$$(76) \qquad H2(t) = \langle a \rangle \cdot (1-DH2) + \langle b \rangle + \langle c \rangle - THC2(t) - THW2(t)$$

where

$$\langle a \rangle = \begin{cases} H2(t-1) & \text{if } t \geq 2 \\ 0 & \text{if } t = 1 \end{cases}$$

$$\langle b \rangle = \begin{cases} TCH2(t-LCH2) & \text{if } t - LCH2 \geq 1 \\ 0 & \text{if } t - LCH2 \leq 0 \end{cases}$$

$$\langle c \rangle = \begin{cases} TWH2(t-LWH2) & \text{if } t - LWH2 \geq 1 \\ 0 & \text{if } t - LWH2 \leq 0 \end{cases}$$

d. Ammunition Stockpile

The interfaces for the domestic and in-theater stockpiles include the prepositioning of ammunition that occurred during the Steady-state interval. The ammunition stockpile equations are:

$$(77) \quad S(t) = \langle a \rangle \cdot (1-DS) + \frac{W1(t)}{KW1} + \frac{W2(t)}{KW2} + \frac{H1(t)}{KH1} + \frac{H2(t)}{KH2} + \sum_{\substack{t-LWH1<s\leq t \\ s\geq 1}} \frac{TWH1(s)}{KW1} + \sum_{\substack{t-LWH2<s\leq t \\ s\geq 1}} \frac{TWH2(s)}{KW2} - DD(t) - PIPE(t)$$

$$(78) \quad SP(t) = \langle b \rangle \cdot (1-DSP) + \langle c \rangle - FD(t)$$

where

$$\langle a \rangle = \begin{cases} ES - EPREP & \text{if } t = 1 \\ S(t-1) & \text{if } t \geq 2 \end{cases}$$

$$\langle b \rangle = \begin{cases} EPREP & \text{if } t = 1 \\ SP(t-1) & \text{if } t \geq 2 \end{cases}$$

$$\langle c \rangle = \begin{cases} PIPE(t-LPIPE) & \text{if } t - LPIPE \geq 1 \\ 0 & \text{if } t - LPIPE \leq 0 \end{cases}$$

Expressions ⟨a⟩ and ⟨b⟩ demonstrate how prepositioned ammunition is removed from the domestic stockpile and placed in the in-theater stockpile by the beginning of the Mobilization/ War period.

Expression ⟨c⟩ is zero if $t - LPIPE \leq 0$ since we have assumed no distinction between the stockpiles, and hence no pipeline, prior to the Mobilization/War period.

e. Costs

The Mobilization/War period costs closely resemble the costs of the core model. They differ in that the discount factor must include the previous two periods and in that salvage values of ammunition held at the end of the war are permitted. This is accomplished by providing two additional cost parameters:

VSSALV = the cost of holding one unit of ammunition in the domestic stockpile during the final time step of the Mobilization/War period (if negative, this represents salvage value).

VSPALV = the cost of holding one unit of ammunition in the in-theater stockpile during the final time step of the Mobilization/War period (if negative, this represents salvage value).

The cost of each activity of the Mobilization/War period is listed in Table 7. Note that the S/PB model provides only ISTEP-1 variables to describe transfers of assets. To provide more would only permit the model to transfer assets beyond the end of the

Table 7. MOBILIZATION/WAR PERIOD COSTS

Variable	Unit Cost	Applicable Time Steps
PC1(t)	$VPC1/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP
PC2(t)	$VPC2/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP
C1(t)	$VC1/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP
C2(t)	$VC2/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP
W1(t)	$VW1/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP
W1(t)/KW1	$VPW1/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP
W2(t)	$VW2/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP
W2(t)/KW1	$VPW2/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP
H1(t)	$VH1/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP
H1(t)/KH1	$VPH1/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP
H2(t)	$VH2/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP
H2(t)/KH2	$VPH2/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP
S(t)	$VS/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP-1
	$VSSALV/(1+R)^{ISTEP+NSS+NPURCH}$	t= ISTEP
SP(t)	$VSP/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP-1
	$VSPALV/(1+R)^{ISTEP+NSS+NPURCH}$	t= ISTEP
PIPE(t)	$VPIPE/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP-1
TCW1(t)	$VCW1/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP-1
TCW2(t)	$VCW2/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP-1
TWH1(t)	$VWH1/(1+R)^{t+NSS+NPURCH} + \frac{VPW1}{KW1} \cdot \frac{1}{(1+R)^{t+NSS+NPURCH}} \cdot \sum_{i=1}^{LWH1} \frac{1}{(1+R)^{i-1}}$	t=1,...,ISTEP-1
TWH2(t)	$VWH2/(1+R)^{t+NSS+NPURCH} + \frac{VPW2}{KW2} \cdot \frac{1}{(1+R)^{t+NSS+NPURCH}} \cdot \sum_{i=1}^{LWH2} \frac{1}{(1+R)^{i-1}}$	t=1,...,ISTEP-1

(continued)

Table 7. (concluded)

Variable	Unit Cost	Applicable Time Steps
TWC1(t)	$VWC1/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP-1
TWC2(t)	$VWC2/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP-1
THC1(t)	$VHC1/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP-1
THC2(t)	$VHC2/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP-1
THW1(t)	$VHW1/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP-1
THW2(t)	$VHW2/(1+R)^{t+NSS+NPURCH}$	t=1,...,ISTEP-1

final time step. As with the core model, warm and hot stocks have two associated costs--maintenance and ammunition production.

The total cost of the Mobilization/War period is, therefore,

$$(77) \quad \sum_{t=1}^{ISTEP} \frac{1}{(1+R)^{t+NSS+NPURCH}} \Big\{ PC1(t)\cdot VPC1 + PC2(t)\cdot VPC2$$

$$+ C1(t)\cdot VC1 + C2(t)\cdot VC2 + W1(t)\cdot(VW1 + \frac{VPW1}{KW1})$$

$$+ W2(t)\cdot(VW2 + \frac{VPW2}{KW2}) + H1(t)\cdot(VH1 + \frac{VPH1}{KH1})$$

$$+ H2(t)\cdot(VH2 + \frac{VPH2}{KH2})\Big\}$$

$$+ \sum_{t=1}^{ISTEP-1} \frac{1}{(1+R)^{t+NSS+NPURCH}} \Big\{ S(t)\cdot VS + SP(t)\cdot VSP$$

$$+ PIPE(t)\cdot VPIPE + TCW1(t)\cdot VCW1 + TCW2(t)\cdot VCW2 + TCH1(t)\cdot VCH1$$

$$+ TCH2(t)\cdot VCH2 + TWH1(t)\cdot \Big\{ VWH1 + \frac{VPW1}{KW1} \cdot \sum_{i=1}^{LWH1} \frac{1}{(1+R)^{i-1}} \Big\}$$

$$+ TWH2(t)\cdot \Big\{ VWH2 + \frac{VPW2}{KW2} \cdot \sum_{i=1}^{LWH2} \frac{1}{(1+R)^{i-1}} \Big\}$$

$$+ \; TWC1(t)\cdot VWC1 + TWC2(t)\cdot VWC2$$
$$+ \; THC1(t)\cdot VHC1 + THC2(t)\cdot VHC2 + THW1(t)\cdot VHW1$$
$$+ \; THW2(t)\cdot VHW2 \Big\}$$
$$+ \; S(ISTEP)\cdot \frac{VSSALV}{(1+R)^{ISTEP+NSS+NPURCH}}$$
$$+ \; SP(ISTEP)\cdot \frac{VSPALV}{(1+R)^{ISTEP+NSS+NPURCH}} \, .$$

We will note at this juncture that the objective function of the S/PB model is the sum of the costs of the three periods, although, as we will see in Chapter III, the model provides the user the option of applying multipliers to wartime costs. In particular, these multipliers may equal zero, allowing one to include only peacetime costs in the objective function.

E. ADDITIONAL CONSTRAINTS

Although the equations described above are sufficient to specify the S/PB model, certain constraints have been added to allow the user increased flexibility when experimenting with the model. These additional constraints fall into three general classes. The first class imposes upper bounds on certain activities. The second class limits the strategies available to the model with which to acquire and dispose of resources. The final class comprises budget constraints.

1. Upper Bounds

The upper bounds are imposed on the activities relating to the in-theater stockpile, in particular on the variables EPREP, SP(t), t = 1, ..., ISTEP, and PIPE(t), t = 1, ..., ISTEP. These constraints take the forms:

(77) $EPREP \leq UBPREP$

(79) $SP(t) \leq UBSP(t) \qquad t = 1, \ldots, ISTEP$

(80) $PIPE(t) \leq UBPIPE(t) \qquad t = 1, \ldots, ISTEP - 1$

where

UBPREP = the maximum amount of ammunition that can be prepositioned into the in-theater stockpile

UBSP(t) = the maximum amount of ammunition that can be held in the in-theater stockpile during time step t

UBPIPE(t) = the maximum amount of ammunition that can be transferred from the domestic to the in-theater stockpile beginning at time step t.

The parameters are input by the user and might represent limits on in-theater storage capability or limits of the ability of airlift and/or sealift to transport ammunition.

2. Strategic Constraints

The strategic constraints are characterized by the user's ability to include or delete them from the model at will. Therefore, these constraints only appear if the user so desires.

The first such constraint is actually a set of three inequalities specifying the minimum levels of production and of the stockpiles that must be maintained during the final time step of the Mobilization/War period. Such constraints might be useful as a proxy for a protracted war that extended beyond the explicitly modelled period. These equations take the form:

$$(81) \quad S(ISTEP) \geq ENDS$$

$$(82) \quad SP(ISTEP) \geq ENDSP$$

$$(83) \quad \frac{W1(ISTEP)}{KW1} + \frac{W2(ISTEP)}{KW2} + \frac{H1(ISTEP)}{KH1} + \frac{H2(ISTEP)}{KH2} \geq ENDPRD$$

where

ENDS = the amount of ammunition that must be held in the domestic stockpile during the final time step

ENDSP = the amount of ammunition that must be held in the in-theater stockpile during the final time step

ENDPRD = the level of ammunition production to be achieved during the final time step. Note that production from capital transferring from warm to hot states is not included in this constraint.

In order to examine "rules of thumb" wherein the proper stockpile/production base mix is given by a simple ratio, the user may invoke constraint (84)

(84) $$EC1 + EC2 + EW1 + EW2 = ES \cdot RATIO$$

where

RATIO = the user-specified ratio of total capital to total stockpile to be achieved by the end of the Build-up period.

A final set of constraints allows the user to restrict the families of purchase patterns, particularly those of warm capital, during the Build-up period. These are as follows:.

(85) $$IBW1 + IBW2 = 0$$

(86) $$BW1 + BW2 = 0$$

(87) $$SLPPC1 - SLPNC1 = SLOPC1$$

(88) $$SLPPC2 - SLPNC2 = SLOPC2$$

(89) $$SLPPW1 - SLPNW1 = SLOPW1$$

(90) $$SLPPW2 - SLPNW2 = SLOPW2$$

where

SLOPC1 = the slope desired by the user for the type 1 cold capital purchase pattern

SLOPC2 = the slope desired by the user for the type 2 cold capital purchase pattern

SLOPW1 = the slope desired by the user for the linear component of the type 1 warm capital purchase pattern.

SLOPW2 = the slope desired by the user for the linear component of the type 2 warm capital purchase pattern.

Equations (87) through (90) must be invoked as a group. One should also note that the nonnegativity of the variables requires that if constraint (85) is invoked, both IBW1 and IBW2 must necessarily be zero. The same logic applies to constraint (86).

3. Budget Constraints

The budget constraints impose limits on the undiscounted costs that are incurred by the acquisition of capital and the production of ammunition. Costs associated with other activities are not included. Single constraints apply to the Build-up and Steady-state periods while each time step of the Mobilization/ War period has its associated budget constraints.

a. Build-Up Period

By removing the discounting factors from those costs of the Build-up period that pertain to capital acquisition and ammunition production, we obtain the budget constraint for this period.

$$
\begin{aligned}
(91)\quad & BC1 \cdot (VPC1 \cdot NPURCH) + BC2 \cdot (VPC2 \cdot NPURCH) \\
& + [SLPPC1-SLPNC1] \cdot \left(VPC1 \sum_{i=1}^{NPURCH} (i-1) \right) \\
& + [SLPPC2-SLPNC2] \cdot \left(VPC2 \sum_{i=1}^{NPURCH} (i-1) \right) \\
& + IBW1 \cdot \left(VPC1 + \frac{VPW1}{KW1} \cdot \sum_{i=1}^{NPURCH} (1-DW1)^{i-1} \right) \\
& + IBW2 \cdot \left(VPC2 + \frac{VPW2}{KW2} \cdot \sum_{i=1}^{NPURCH} (1-DW2)^{i-1} \right) \\
& + BW1 \cdot \left(VPC1 \cdot NPURCH + \frac{VPW1}{KW1} \cdot \sum_{i=1}^{NPURCH} \sum_{j=1}^{i} (1-DW1)^{j-1} \right) \\
& + BW2 \cdot \left(VPC2 \cdot NPURCH + \frac{VPW2}{KW2} \cdot \sum_{i=1}^{NPURCH} \sum_{j=1}^{i} (1-DW2)^{j-1} \right) \\
& + [SLPPW1-SLPNW1] \cdot \left(VPC1 \cdot \sum_{i=1}^{NPURCH} (i-1) + \frac{VPW1}{KW1} \cdot \sum_{i=1}^{NPURCH} \sum_{j=1}^{i-1} j(1-DW1)^{i-1-j} \right) \\
& + [SLPPW2-SLPNW2] \cdot \left(VPC2 \cdot \sum_{i=1}^{NPURCH} (i-1) + \frac{VPW2}{KW2} \cdot \sum_{i=1}^{NPURCH} \sum_{j=1}^{i-1} j(1-DW2)^{i-1-j} \right) \\
& \leq BPBUDG
\end{aligned}
$$

where

BPBUDG = the user-supplied limit on the Build-up period capital purchase and ammunition production costs (undiscounted).

b. Steady-State Period

In like manner, we determine the Steady-state period budget constraint to be

$$
\begin{aligned}
(92)\quad & EC1 \cdot (VPC1 \cdot DC1 \cdot NSS) + EC2 \cdot (VPC2 \cdot DC2 \cdot NSS) \\
& + EW1 \cdot \left(VPC1 \cdot DW1 \cdot NSS + \frac{VPW1}{KW1} \cdot NSS\right) \\
& + EW2 \cdot \left(VPC2 \cdot DW2 \cdot NSS + \frac{VPW2}{KW2} \cdot NSS\right) \\
& \leq EBUDG
\end{aligned}
$$

where

EBUDG = the user-supplied limit on the Steady-state period capital purchase and ammunition production costs (undiscounted).

c. Mobilization/War Period

For each time step t of the Mobilization/War period, there is a budget constraint of the following form:

$$
\begin{aligned}
(93)\quad & PC1(t) \cdot VPC1 + PC2(t) \cdot VPC2 \\
& + W1(t) \cdot \frac{VPW1}{KW1} + W2(t) \cdot \frac{VPW2}{KW2} \\
& + H1(t) \cdot \frac{VPH1}{KW1} + H2(t) \cdot \frac{VPH2}{KW2} \\
& + \frac{VPW1}{KW1} \cdot \sum_{\substack{t-LWH1<s\leq t \\ s\geq 1}} TWH1(s) + \frac{VPW2}{KW2} \cdot \sum_{\substack{t-LWH2<s\leq t \\ s\geq 1}} TWH2(s) \\
& \leq BUDG(t)
\end{aligned}
$$

where

BUDG(t) = the user-supplied limit on the undiscounted costs of capital purchase and ammunition production applying to time step t.

F. MODEL SUMMARY

For completeness, we restate in this section the variables, the objective function, and constraints of the S/PB model. Although, as before, we use numbers in bent brackets (⟨·⟩) to represent constraints and expressions, the reader may, if he so chooses, substitute the terms so represented by the numbers and write down the model explicitly. We adopt this approach to save space.

The constraints are given in the order in which they have been programmed into the computer implementation of this model. This order is arbitrary. Recall that ISTEP is the number of time steps in the Mobilization/War period.

Variables

The variables of the S/PB model are:

BC1	SLPPW1
BC2	SLPNW1
SLPPC1	SLPPW2
SLPNC1	SLPNW2
SLPPC2	EC1
SLPNC2	EC2
IBW1	EW1
IBW2	EW2
BW1	ES
BW2	EPREP

(continued on next page)

C1(t)	t = 1, ..., ISTEP
C2(t)	t = 1, ..., ISTEP
W1(t)	t = 1, ..., ISTEP
W2(t)	t = 1, ..., ISTEP
H1(t)	t = 1, ..., ISTEP
H2(t)	t = 1, ..., ISTEP
S(t)	t = 1, ..., ISTEP
SP(t)	t = 1, ..., ISTEP
TCW1(t)	t = 1, ..., ISTEP - 1
TCW2(t)	t = 1, ..., ISTEP - 1
TCH1(t)	t = 1, ..., ISTEP - 1
TCH2(t)	t = 1, ..., ISTEP - 1
TWH1(t)	t = 1, ..., ISTEP - 1
TWH2(t)	t = 1, ..., ISTEP - 1
TWC1(t)	t = 1, ..., ISTEP - 1
TWC2(t)	t = 1, ..., ISTEP - 1
THC1(t)	t = 1, ..., ISTEP - 1
THC2(t)	t = 1, ..., ISTEP - 1
THW1(t)	t = 1, ..., ISTEP - 1
THW2(t)	t = 1, ..., ISTEP - 1
PIPE(t)	t = 1, ..., ISTEP - 1

Objective Function

(94) Minimize (over all variables)

$$\begin{aligned}
&\{BC1 \cdot \langle 23 \rangle + BC2 \cdot \langle 24 \rangle + (SLPPC1-SLPNC1) \cdot \langle 27 \rangle \\
&+ (SLPPC2-SLPNC2) \cdot \langle 28 \rangle + IBW1 \cdot \langle 34 \rangle + IBW2 \cdot \langle 35 \rangle \\
&+ BW1 \cdot \langle 41 \rangle + BW2 \cdot \langle 42 \rangle + (SLPPW1-SLPNW1) \cdot \langle 48 \rangle \\
&+ (SLPPW2-SLPNW2) \cdot \langle 49 \rangle + EC1 \cdot \langle 62 \rangle + EC2 \cdot \langle 63 \rangle \\
&+ EW1 \cdot \langle 67 \rangle + EW2 \cdot \langle 68 \rangle + ES \cdot \langle 69 \rangle + EPREP \cdot \langle 70 \rangle + \langle 77 \rangle\}
\end{aligned}$$

subject to:

Warm Capital Acquisition

(95) $\langle 52 \rangle$

(96) $\langle 53 \rangle$

Capital Conservation from Build-up through Steady-state

(97) $\langle 56 \rangle$

(98) $\langle 57 \rangle$

Ammunition Acquisition

(99) $\langle 50 \rangle$

Satisfaction of Build-up Period Demand

(100) $\langle 19 \rangle$

(101) $\langle 20 \rangle$

Prepositioning Limitation

(102) $\langle 58 \rangle$

Prepositioning Upper Bound

(103) $\langle 78 \rangle$

Mobilization/War Cold Stocks

(104) $\langle 71 \rangle$ (ISTEP equations)

(105) $\langle 72 \rangle$ (ISTEP equations)

Mobilization/War Warm Stocks

(106) $\langle 73 \rangle$ (ISTEP equations)

(107) $\langle 74 \rangle$ (ISTEP equations)

Mobilization/War Hot Stocks

(108) $\langle 75 \rangle$ (ISTEP equations)

(109) $\langle 76 \rangle$ (ISTEP equations)

Mobilization/War Domestic Stockpile

(110) $\langle 77 \rangle$ (ISTEP equations)

Mobilization/War In-Theater Stockpile

(111) $\langle 78 \rangle$ (ISTEP equations)

Foreign Stockpile Upper Bounds

(112) $\langle 79 \rangle$ (ISTEP inequalities)

Pipeline Upper Bounds

(113) $\langle 80 \rangle$ (ISTEP-1 inequalities)

Mobilization/War Budget Constraints

(114) $\langle 89 \rangle$ (ISTEP inequalities)

Build-up Budget Constraint

(115) $\langle 87 \rangle$

Steady-State Budget Constraint

(116) $\langle 88 \rangle$

Nonnegative Purchase Requirements

(117) $\langle 15 \rangle$

(118) $\langle 16 \rangle$

(119) $\langle 17 \rangle$

(120) $\langle 18 \rangle$

Final Value Constraints (optional)

(121) $\langle 81 \rangle$

(122) $\langle 82 \rangle$

(123) $\langle 83 \rangle$

Purchase Pattern Slope Constraints (optional)

(124) $\langle 87 \rangle$

(125) $\langle 88 \rangle$

(126) $\langle 89 \rangle$

(127) $\langle 90 \rangle$

Capital-to-Stockpile Ratio Constraint

(128) $\langle 84 \rangle$

Satisfaction of Steady-State Demands

(129) $\langle 51 \rangle$

No Level Warm Capital Buy Constraint (optional)

(130) $\langle 86 \rangle$

No Initial Warm Capital Buy Constraint (optional)

(131) $\langle 85 \rangle$

In addition to these constraints, we require that all variables be nonnegative.

III. IMPLEMENTATION AND USER'S GUIDE

The S/PB model, as formulated in the preceding chapter, presents a linear programming problem to which the well-known techniques of linear programming can be applied to obtain a set of variable values minimizing the objective function. We solve this linear programming problem using the linear programming subroutines of a code that solves, by branch-and-bound, separable piecewise-linear programming problems. This program, named MOGG, is documented in Reference [1]. There are two reasons for adopting this approach:

1. It is a simple matter to employ MOGG as a linear programming routine.
2. Minor modifications allow one to replace some linear terms with piecewise-linear functions of the variables, thereby enabling one to investigate certain nonlinear formulations of the model. This is a possible future effort.

The model has been implemented by reprogramming the initial section of MOGG in such a way as to replace MOGG's input code with code that constructs MOGG input from S/PB input.

We will not discuss programming considerations in detail here; however, it may be useful to the user of the model to know that the linear programming tableau is filled by columns. First is a section of columns corresponding to artificial variables followed by columns corresponding to model variables in the following order:

Column number(s) (after artificial variable(s))	Variable(s)
1	BC1
2	BC2
3	BW1
4	BW2
5	SLPPC1
6	SLPNC1
7	SLPPC2
8	SLPNC2
9	SLPPW1
10	SLPNW1
11	SLPPW2
12	SLPNW2
13	EC1
14	EC2
15	EW1
16	EW2
17	ES
18	EPREP
19 to 18 + ISTEP	C1(t) (t=1,...,ISTEP)
19 + ISTEP to 18 + 2ISTEP	C2(t) (t=1,...,ISTEP)
19 + 2ISTEP to 18 + 3ISTEP	W1(t) (t=1,...,ISTEP)
19 + 3ISTEP to 18 + 4ISTEP	W2(t) (t=1,...,ISTEP)
19 + 4ISTEP to 18 + 5ISTEP	H1(t) (t=1,...,ISTEP)
19 + 5ISTEP to 18 + 6ISTEP	H2(t) (t=1,...,ISTEP)
19 + 6ISTEP to 18 + 7ISTEP	PC1(t) (t=1,...,ISTEP)
19 + 7ISTEP to 18 + 8ISTEP	PC2(t) (t=1,...,ISTEP)
19 + 8ISTEP to 18 + 9ISTEP	S(t) (t=1,...,ISTEP)
19 + 9ISTEP to 18 + 10ISTEP	SP(t) (t=1,...,ISTEP)
19 + 10ISTEP to 17 + 11ISTEP	PIPE(t) (t=1,...,ISTEP-1)
18 + 11ISTEP to 16 + 12ISTEP	TCW1(t) (t=1,...,ISTEP-1)
17 + 12ISTEP to 15 + 13ISTEP	TCW2(t) (t=1,...,ISTEP-1)

Column number(s) (after artificial variable(s))	Variable(s)	
16 + 13ISTEP to 14 + 14ISTEP	TCH1(t)	(t=1,...,ISTEP-1)
15 + 14ISTEP to 13 + 15ISTEP	TCH2(t)	(t=1,...,ISTEP-1)
14 + 15ISTEP to 12 + 16ISTEP	TWH1(t)	(t=1,...,ISTEP-1)
13 + 16ISTEP to 11 + 17ISTEP	TWH2(t)	(t=1,...,ISTEP-1)
12 + 17ISTEP to 10 + 18ISTEP	TWC1(t)	(t=1,...,ISTEP-1)
11 + 18ISTEP to 9 + 19ISTEP	TWC2(t)	(t=1,...,ISTEP-1)
10 + 19ISTEP to 8 + 20ISTEP	THC1(t)	(t=1,...,ISTEP-1)
9 + 20ISTEP to 7 + 21ISTEP	THC2(t)	(t=1,...,ISTEP-1)
8 + 21ISTEP to 6 + 22ISTEP	THW1(t)	(t=1,...,ISTEP-1)
7 + 22ISTEP to 5 + 23ISTEP	THW2(t)	(t=1,...,ISTEP-1)
6 + 23ISTEP	IBW1	
7 + 23ISTEP	IBW2	

A. USING THE MODEL

The first card of the input deck is a title card. Any fifty character title is acceptable. Following the title card are the inputs required to run the S/PB model, which are listed below in the order in which they are read. After each bullet (•) is a list of parameter values that must appear on the card or cards as well as the applicable FORTRAN format statement. Only those parameters that are not defined in Chapter II are defined here.

- IXPRIN, K1, K2, K3, K4, K5, KC1, KC2, KC3, KC4
  FORMAT (10I5)

  IXPRIN = K1 = K2 = K3 = k4 = K5 = 0

  The first six entries are MOGG options, which are explained in Reference [1]. Except for debugging purposes, they should all be set to zero. The next four entries are the means with which the user imposes the optional constants.

$$KC1 = \begin{cases} 1 \text{ if the user wishes to include the final value constraints (equations (121)-(123))} \\ 0 \text{ otherwise.} \end{cases}$$

$$KC2 = \begin{cases} 1 & \text{if the user wishes to include the purchase pattern shape constraints (Equations (124)-(127)).} \\ 0 & \text{otherwise.} \end{cases}$$

$$KC3 = \begin{cases} 1 & \text{if the user wishes to include the capital to stockpile ratio constraint (Equation (128)).} \\ 0 & \text{otherwise.} \end{cases}$$

$$KC4 = \begin{cases} 2 & \text{if the user wishes to include the no-level-warm-capital purchase constraint (Equation (130)).} \\ 1 & \text{if the user wishes to include the no-initial-warm-capital purchase constraint (Equation (131)).} \\ 0 & \text{otherwise.} \end{cases}$$

- NLAG, NPURCH, NSS, ISTEP
  FORMAT (4I5)

  NPURCH may assume any positive integer value. NSS and NLAG may be any nonnegative integer value. ISTEP is limited to integer values between 1 and 36 (because of core storage limitations).

- VC1, VC2, VW1, VW2, VPW1, VPW2, VH1, VH2
  FORMAT (8F10.4)

- VPH1, VPH2, VPC1, VPC2, VCW1, VCW2, VCH1, VCH2
  FORMAT (8F10.4)

- VWH1, VWH2, VWC1, VWC2, VHC1, VHC2, VHW1, VHW2
  FORMAT (8F10.4)

- VPIPE, VS, VSSALV, VSP, VSPALV, VPREP, R
  FORMAT (7F10.4)

- MA, MB, AMULT, BMULT
  FORMAT (2I5, 2F10.3).

These last four entries are included to offer the user the opportunity to investigate the effect of weighting certain costs of the Mobilization/War period. For instance, one might wish to determine the optimal stockpile/production base mix where wartime costs are excluded from the objective function.

Let t = 1, ..., ISTEP denote the time steps of the Mobilization/War period. The unit costs corresponding to time steps t such that MA $\leq$ t < MB are multiplied by AMULT. Those costs corresponding to time steps t for which MB $\leq$ t $\leq$ ISTEP are multiplied by BMULT.

- KW1, KW2, KH1, KH2
  FORMAT (4F10.4)

- DC1, DC2, DW1, DW2, DH1, DH2, DS, DSP
  FORMAT (15I5)

- LP1, LP2, LCW1, LCW2, LCH1, LCH2, LWH1, LWH2, LHC1, LHC2, LHW1, LHW2, LWC1, LWC2, LPIPE
  FORMAT (16I5)

  In order to prevent a resource from appearing in two places during any one time step, all these time lags should be at least 1.

- OMUN, OCOLD1, OCOLD2, OWARM1, OWARM2
  FORMAT (5F10.4)

- BPBUG, EBUDG
- BUDG(1),...,BUDG(ISTEP)
  FORMAT (8F10.4)

  More than two cards will be necessary if ISTEP is greater than 8.

- BPDEM, SSDEM
- DD(1),...,DD(ISTEP)
- FD(1),...,FD(ISTEP)
  FORMAT (8F10.4)

More than three cards will be necessary if ISTEP is greater than 8.

- UBPREP
- UBSP(1),...,UBSP(ISTEP)
- UBPIPE(1),...,UBPIPE(ISTEP-1)

More than three cards will be necessary if ISTEP is greater than 8.

Optional Cards

If KC1 = 1, include

- ENDS, ENDSP, ENDPROD
  FORMAT (3F10.4)

If KC2 = 1, include

- SLOPC1, SLOPC2, SLOPW1, SLOPW2
  FORMAT (4F10.4)

If KC3 = 1, include

- RATIO
  FORMAT (1F10.4)

Run times of the model on the CDC 6400 computer are on the order of 100 CPU seconds.

Output consists of three sections. The first restates the inputs and also contains a statement of production costs attributable to original warm capital stocks. The second section is MOGG output and, for those unfamiliar with Reference [1], may be ignored. The final section gives the value of the objective function at optimum and the optimal variable values.

B. SAMPLE RUN

Figure 5 shows a sample input deck. Note that, for this run, the Build-up period lasts a total of 60 time steps, with 30 of those required before new capital can produce. The Steady-state period is 180 time steps and the Mobilization/War period is 24. Also, the user has set the final value constraints such that the domestic stockpile must have in it at least 277.31302 units in the final time period. Notice also the negative entries for VSSALV and VSPALV, indicating that at the end of the Mobilization/War period, the salvage value of ammunition remaining in the stockpile is subtracted from the total costs.

The output of the S/PB model for this sample run is displayed in Figure 6. The output has been annotated to highlight certain features.

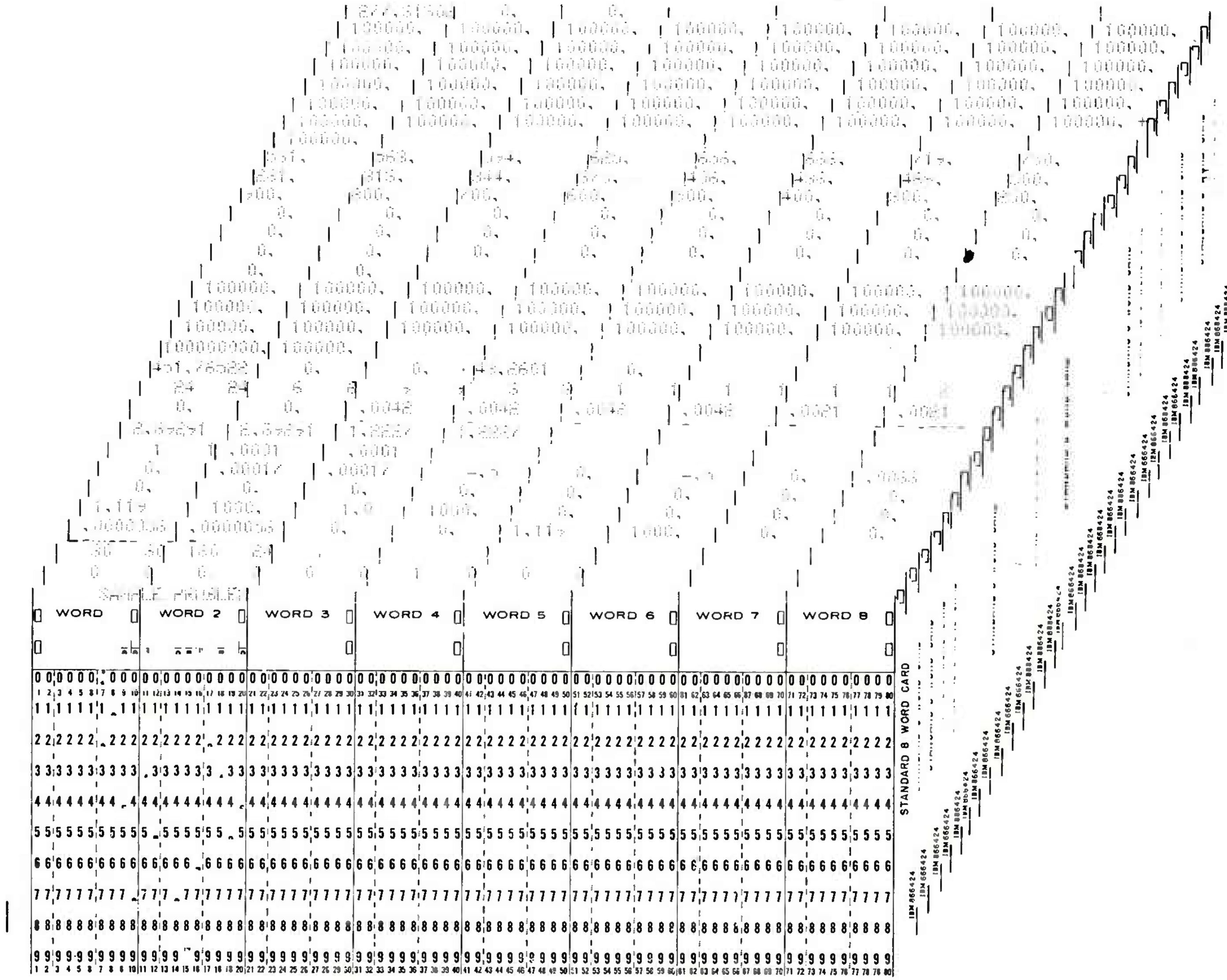

Figure 5. SAMPLE INPUT DECK

```
IDA STOCKPILE/PRODUCTION BASE MODEL -- TITLE
     SAMPLE PROBLEM

FINAL PERIOD STOCKPILES AND PRODUCTION HAVE BEEN SET--Listing of optional constraints that have been requested

NLAG=    30      NPUPCH=    30      NSS=   180      TSTEP=    24

COSTS ****************************************************

VC1          VC2          VW1          VW2          VPW1         VPW2          VH1          VH2
    .0000        .0000      0.0000       0.0000       1.1190     1000.0000       0.0000       0.0000

VPH1         VPH2         VPC1         VPC2         VCW1         VCW2          VCH1         VCH2
   1.1190    1000.0000      1.0000    1000.0000       0.0000       0.0000        0.0000       0.0000

VWH1         VWH2         VWC1         VWC2         VHC1         VHC2          VHW1         VHW2
   0.0000       0.0000      0.0000       0.0000       0.0000       0.0000        0.0000       0.0000

VPIPE        VS           VSP          VSSALV       VSPALV       VBSALV        VPREP        R
   0.0000       .0002       .0002       -.5000       0.0000       -.5000        0.0000        .0083

MA           MB           AMULT        BMULT
   1            1            .0001        .0001

CAPITAL/OUTPUT RATIOS *********************************

KW1          KW2          KH1          KH2
    2.893        2.893       1.223        1.223

DETERIORATION RATES ***********************************

DC1          DC2          DW1          DW2          DH1          DH2           DS           DSP
    0.000        0.000        .004         .004         .004         .004          .002         .002

TIME LAGS ***********************************************

LP1  LP2  LCW1  LCW2  LCH1  LCH2  LWH1  LWH2  LHC1  LHC2  LHW1  LHW2  LWC1  LWC2  LPIPE
 24   24    6     6     9     9     3     3     1     1     1     1     1     1     2

ORIGINALS ***********************************************

OMUN          OCOLD1        OCOLD2        OWARM1        OWARM2
  451.7652       0.0000        0.0000       43.2601        0.0000

        PRODUCTION DURING NLAG =    448.6151

        INVENTORY AFTER NLAG =  900.3803

BUDGETS *************************************************

BPBUDG= 100000000.000

ERUDG=   100000.000

BUDG=   100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000
BUDG=   100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000
```

REITERATION OF INPUT

Figure 6. SAMPLE PROBLEM OUTPUT

?

```
BUDG=     100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000

DEMANDS ****************************************************
BPDEM=         0.0000
SSDEM=         0.0000
DD=            0.000         0.000         0.000         0.000         0.000         0.000         0.000         0.000
DD=            0.000         0.000         0.000         0.000         0.000         0.000         0.000         0.000
DD=            0.000         0.000         0.000         0.000         0.000         0.000         0.000         0.000
FD=          900.000       800.000       700.000       600.000       500.000       400.000       300.000       250.000
FD=          281.000       313.000       344.000       375.000       406.000       438.000       469.000       500.000
FD=          531.000       563.000       594.000       625.000       656.000       688.000       719.000       750.000

UPPER BOUNDS ***********************************************
UBPRFP=   100000.0000
UBSP=     100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000
UBSP=     100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000
UBSP=     100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000
UBPIPE=     100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000
UBPIPE=     100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000
UBPIPE=     100000.000    100000.000    100000.000    100000.000    100000.000    100000.000    100000.000

OPTIONAL INFORMATION ***************************************
ENDS=     277.3130  ENDSP=      0.0000  ENDPHU=      0.0000      Information pertaining to optional constraints

PRODUCTION COSTS FROM ORIGINAL WARM1=     708.346  PRODUCTON COSTS FROM ORIGINAL WARM2=     0.000 --Fixed costs independent
                                                                                                of variable values
```

REITERATION OF INPUT

Figure 6. (contd)

```
PROBLEM INFORMATION

                        283ROWS
                        559VARIABLES
                          5     LP PROBLEMS WILL BE SOLVED

ROW TYPE--
 0 1 1-1-1-1 1 1 1 1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
-1-1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1-1

CONVEXITY FLAGS--

0000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000
000000000000000000000000000000000000000

VARIABLE CARDS REPRODUCED--


RHS CARD(S) REPRODUCED--
   0.         38.29       0.          38.29       0.         -1257        14.95       13.24
   0.         1.0000E+05  0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          0.          0.          0.          0.          0.          0.
   0.         0.          900.0       800.0       700.0       600.0       500.0       400.0
   300.0      250.0       281.0       313.0       344.0       375.0       406.0       438.0
   469.0      500.0       531.0       563.0       594.0       625.0       656.0       688.0
   719.0      750.0       1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05
1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05
1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05
1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05
1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05
1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05
1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05
1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05  1.0000E+05
```


Figure 6. (contd)

MOGG OUTPUT

1.0000E+05	1.0000E+05	1.0000E+05	1.0000E+05	1.0000E+05	1.0000E+05	1.0000E+05	1.0000E+05
1.0000E+05	1.0000E+05	1.0000E+05	0.	0.	0.	0.	-277.3
-0.	-0.	0.					

Figure 6. (contd)

STARTING TO ITERATE

STAGE.PROBLEM	LOWER BOUND	UPPER BOUND	BRANCHING VARIABLE		MDGG OUTPUT
0.0	4697	4697	0	STABILITY COUNT =	0

OBJECTIVE FUNCTION AT OPTIMUM 4697

TOTAL DISCOUNTED COSTS= 5465.017 -- Cost at optimal variable values

VARIABLE VALUES AT OPTIMUM--

BUILD-UP PERIOD **

Build-up period variable values

IRW1= 0.000 IRW2= 0.000

BC1= 0.000 BC2= 0.000 BW1= 3.212 BW2= 0.000

SLOPEC1= 0.000 SLOPEC2= 0.000 SLOPEW1= 1.766 SLOPEW2= 0.000

STEADY-STATE PERIOD **

Steady-state period variable values

EC1= 841.511 EC2= 0.000 EW1= 26.542 EW2= 0.000 TOTAL CAPITAL= 868.053

ES= 4369.036 EPREP= 1751.684

BASE/STOCKPILE RATIO= .190

WARTIME PERIOD **

MOBILIZATION/WAR PERIOD VARIABLE VALUES

C1(1)=	0.000	C2(1)=	0.000	W1(1)=	0.000	W2(1)=	0.000	H1(1)=	0.000
C1(2)=	0.000	C2(2)=	0.000	W1(2)=	0.000	W2(2)=	0.000	H1(2)=	0.000
C1(3)=	0.000	C2(3)=	0.000	W1(3)=	0.000	W2(3)=	0.000	H1(3)=	0.000
C1(4)=	0.000	C2(4)=	0.000	W1(4)=	0.000	W2(4)=	0.000	H1(4)=	26.542
C1(5)=	0.000	C2(5)=	0.000	W1(5)=	0.000	W2(5)=	0.000	H1(5)=	26.542
C1(6)=	0.000	C2(6)=	-0.000	W1(6)=	0.000	W2(6)=	0.000	H1(6)=	26.542
C1(7)=	0.000	C2(7)=	0.000	W1(7)=	0.000	W2(7)=	0.000	H1(7)=	26.542
C1(8)=	0.000	C2(8)=	0.000	W1(8)=	0.000	W2(8)=	0.000	H1(8)=	26.542
C1(9)=	0.000	C2(9)=	0.000	W1(9)=	.111	W2(9)=	0.000	H1(9)=	26.542
C1(10)=	.111	C2(10)=	0.000	W1(10)=	.111	W2(10)=	0.000	H1(10)=	611.752
C1(11)=	138.715	C2(11)=	0.000	W1(11)=	0.000	W2(11)=	0.000	H1(11)=	609.294
C1(12)=	138.827	C2(12)=	0.000	W1(12)=	0.000	W2(12)=	0.000	H1(12)=	606.735
C1(13)=	138.938	C2(13)=	0.000	W1(13)=	0.000	W2(13)=	0.000	H1(13)=	604.298
C1(14)=	139.050	C2(14)=	0.000	W1(14)=	0.000	W2(14)=	0.000	H1(14)=	719.791
C1(15)=	0.000	C2(15)=	0.000	W1(15)=	.000	W2(15)=	0.000	H1(15)=	716.879
C1(16)=	.111	C2(16)=	0.000	W1(16)=	.000	W2(16)=	0.000	H1(16)=	713.980
C1(17)=	.223	C2(17)=	0.000	W1(17)=	.000	W2(17)=	0.000	H1(17)=	711.093
C1(18)=	0.000	C2(18)=	0.000	W1(18)=	0.000	W2(18)=	0.000	H1(18)=	708.217
C1(19)=	.111	C2(19)=	0.000	W1(19)=	-.000	W2(19)=	0.000	H1(19)=	705.243
C1(20)=	.223	C2(20)=	0.000	W1(20)=	.000	W2(20)=	0.000	H1(20)=	702.281
C1(21)=	.334	C2(21)=	0.000	W1(21)=	0.000	W2(21)=	0.000	H1(21)=	699.331

Figure 6. (contd)

C1(22)=	.446	C2(22)=	0.000	W1(22)=	.000	W2(22)=	0.000	H1(22)=	694.394
C1(23)=	.557	C2(23)=	0.000	W1(23)=	.000	W2(23)=	0.000	H1(23)=	0.000
C1(24)=	.669	C2(24)=	0.000	W1(24)=	693.804	W2(24)=	0.000	H1(24)=	139.161
H2(1)=	0.000	PC1(1)=	0.000	PC2(1)=	0.000	S(1)=	1976.527	SP(1)=	801.684
H2(2)=	0.000	PC1(2)=	0.000	PC2(2)=	0.000	S(2)=	1381.590	SP(2)=	0.000
H2(3)=	0.000	PC1(3)=	0.000	PC2(3)=	0.000	S(3)=	887.941	SP(3)=	0.000
H2(4)=	0.000	PC1(4)=	0.000	PC2(4)=	0.000	S(4)=	507.900	SP(4)=	0.000
H2(5)=	0.000	PC1(5)=	0.000	PC2(5)=	0.000	S(5)=	228.657	SP(5)=	0.000
H2(6)=	0.000	PC1(6)=	0.000	PC2(6)=	0.000	S(6)=	0.000	SP(6)=	0.000
H2(7)=	0.000	PC1(7)=	0.000	PC2(7)=	0.000	S(7)=	31.711	SP(7)=	0.000
H2(8)=	0.000	PC1(8)=	0.000	PC2(8)=	0.000	S(8)=	31.355	SP(8)=	0.000
H2(9)=	0.000	PC1(9)=	0.000	PC2(9)=	0.000	S(9)=	0.000	SP(9)=	0.000
H2(10)=	0.000	PC1(10)=	0.000	PC2(10)=	0.000	S(10)=	0.000	SP(10)=	0.000
H2(11)=	0.000	PC1(11)=	0.000	PC2(11)=	0.000	S(11)=	258.222	SP(11)=	0.000
H2(12)=	0.000	PC1(12)=	0.000	PC2(12)=	0.000	S(12)=	356.667	SP(12)=	125.406
H2(13)=	0.000	PC1(13)=	0.000	PC2(13)=	0.000	S(13)=	421.951	SP(13)=	0.000
H2(14)=	0.000	PC1(14)=	0.000	PC2(14)=	0.000	S(14)=	509.832	SP(14)=	0.000
H2(15)=	0.000	PC1(15)=	0.000	PC2(15)=	0.000	S(15)=	0.000	SP(15)=	0.000
H2(16)=	0.000	PC1(16)=	0.000	PC2(16)=	0.000	S(16)=	584.014	SP(16)=	0.000
H2(17)=	0.000	PC1(17)=	0.000	PC2(17)=	0.000	S(17)=	570.402	SP(17)=	564.185
H2(18)=	0.000	PC1(18)=	0.000	PC2(18)=	0.000	S(18)=	523.428	SP(18)=	0.000
H2(19)=	0.000	PC1(19)=	0.000	PC2(19)=	0.000	S(19)=	443.120	SP(19)=	0.000
H2(20)=	0.000	PC1(20)=	0.000	PC2(20)=	0.000	S(20)=	328.559	SP(20)=	0.000
H2(21)=	0.000	PC1(21)=	0.000	PC2(21)=	0.000	S(21)=	180.825	SP(21)=	0.000
H2(22)=	0.000	PC1(22)=	0.000	PC2(22)=	0.000	S(22)=	0.000	SP(22)=	0.000
H2(23)=	0.000	PC1(23)=	0.000	PC2(23)=	0.000	S(23)=	.000	SP(23)=	0.000
H2(24)=	0.000	PC1(24)=	0.000	PC2(24)=	0.000	S(24)=	353.644	SP(24)=	0.000
PIPE(1)=	700.000	TCW1(1)=	841.622	TCW2(1)=	0.000	TCH1(1)=	0.000	TCH2(1)=	0.000
PIPE(2)=	600.000	TCW1(2)=	.111	TCW2(2)=	0.000	TCH1(2)=	0.000	TCH2(2)=	0.000
PIPE(3)=	500.000	TCW1(3)=	.111	TCW2(3)=	0.000	TCH1(3)=	0.000	TCH2(3)=	0.000
PIPE(4)=	400.000	TCW1(4)=	0.000	TCW2(4)=	0.000	TCH1(4)=	.111	TCH2(4)=	0.000
PIPE(5)=	300.000	TCW1(5)=	0.000	TCW2(5)=	0.000	TCH1(5)=	.111	TCH2(5)=	0.000
PIPE(6)=	250.000	TCW1(6)=	0.000	TCW2(6)=	0.000	TCH1(6)=	.111	TCH2(6)=	0.000
PIPE(7)=	281.000	TCW1(7)=	.111	TCW2(7)=	0.000	TCH1(7)=	0.000	TCH2(7)=	0.000
PIPE(8)=	313.000	TCW1(8)=	.111	TCW2(8)=	0.000	TCH1(8)=	0.000	TCH2(8)=	0.000
PIPE(9)=	344.000	TCW1(9)=	.111	TCW2(9)=	0.000	TCH1(9)=	0.000	TCH2(9)=	0.000
PIPE(10)=	500.406	TCW1(10)=	0.000	TCW2(10)=	0.000	TCH1(10)=	0.000	TCH2(10)=	0.000
PIPE(11)=	280.858	TCW1(11)=	0.000	TCW2(11)=	0.000	TCH1(11)=	0.000	TCH2(11)=	0.000
PIPE(12)=	438.000	TCW1(12)=	0.000	TCW2(12)=	0.000	TCH1(12)=	0.000	TCH2(12)=	0.000
PIPE(13)=	469.000	TCW1(13)=	0.000	TCW2(13)=	0.000	TCH1(13)=	0.000	TCH2(13)=	0.000
PIPE(14)=	500.000	TCW1(14)=	0.000	TCW2(14)=	0.000	TCH1(14)=	0.000	TCH2(14)=	0.000
PIPE(15)=	1095.185	TCW1(15)=	0.000	TCW2(15)=	0.000	TCH1(15)=	139.141	TCH2(15)=	0.000
PIPE(16)=	0.000	TCW1(16)=	0.000	TCW2(16)=	0.000	TCH1(16)=	0.000	TCH2(16)=	0.000
PIPE(17)=	594.000	TCW1(17)=	0.000	TCW2(17)=	0.000	TCH1(17)=	0.000	TCH2(17)=	0.000
PIPE(18)=	625.000	TCW1(18)=	.334	TCW2(18)=	0.000	TCH1(18)=	0.000	TCH2(18)=	0.000
PIPE(19)=	656.000	TCW1(19)=	0.000	TCW2(19)=	0.000	TCH1(19)=	0.000	TCH2(19)=	0.000
PIPE(20)=	688.000	TCW1(20)=	0.000	TCW2(20)=	0.000	TCH1(20)=	0.000	TCH2(20)=	0.000
PIPE(21)=	719.000	TCW1(21)=	0.000	TCW2(21)=	0.000	TCH1(21)=	0.000	TCH2(21)=	0.000
PIPE(22)=	750.000	TCW1(22)=	0.000	TCW2(22)=	0.000	TCH1(22)=	0.000	TCH2(22)=	0.000
PIPE(23)=	0.000	TCW1(23)=	0.000	TCW2(23)=	0.000	TCH1(23)=	0.000	TCH2(23)=	0.000
TWH1(1)=	26.542	TWH2(1)=	0.000	TWC1(1)=	0.000	TWC2(1)=	0.000	THC1(1)=	0.000
TWH1(2)=	.111	TWH2(2)=	0.000	TWC1(2)=	0.000	TWC2(2)=	0.000	THC1(2)=	0.000
TWH1(3)=	.111	TWH2(3)=	0.000	TWC1(3)=	0.000	TWC2(3)=	0.000	THC1(3)=	0.000
TWH1(4)=	.111	TWH2(4)=	0.000	TWC1(4)=	0.000	TWC2(4)=	0.000	THC1(4)=	0.000
TWH1(5)=	.111	TWH2(5)=	0.000	TWC1(5)=	0.000	TWC2(5)=	0.000	THC1(5)=	0.000
TWH1(6)=	.111	TWH2(6)=	0.000	TWC1(6)=	0.000	TWC2(6)=	0.000	THC1(6)=	0.000
TWH1(7)=	841.622	TWH2(7)=	0.000	TWC1(7)=	0.000	TWC2(7)=	0.000	THC1(7)=	0.000
TWH1(8)=	.111	TWH2(8)=	0.000	TWC1(8)=	0.000	TWC2(8)=	0.000	THC1(8)=	0.000
TWH1(9)=	0.000	TWH2(9)=	0.000	TWC1(9)=	0.000	TWC2(9)=	0.000	THC1(9)=	0.000
TWH1(10)=	0.000	TWH2(10)=	0.000	TWC1(10)=	0.000	TWC2(10)=	0.000	THC1(10)=	138.492
TWH1(11)=	117.919	TWH2(11)=	0.000	TWC1(11)=	0.000	TWC2(11)=	0.000	THC1(11)=	0.000

Figure 6. (contd)

TWH1(12)=	.000	TWH2(12)=	0.000	TWC1(12)=	0.000	TWC2(12)=	0.000
TWH1(13)=	.111	TWH2(13)=	0.000	TWC1(13)=	0.000	TWC2(13)=	0.000
TWH1(14)=	.111	TWH2(14)=	0.000	TWC1(14)=	0.000	TWC2(14)=	0.000
TWH1(15)=	.111	TWH2(15)=	0.000	TWC1(15)=	0.000	TWC2(15)=	0.000
TWH1(16)=	0.000	TWH2(16)=	0.000	TWC1(16)=	0.000	TWC2(16)=	0.000
TWH1(17)=	0.000	TWH2(17)=	0.000	TWC1(17)=	0.000	TWC2(17)=	0.000
TWH1(18)=	0.000	TWH2(18)=	0.000	TWC1(18)=	0.000	TWC2(18)=	0.000
TWH1(19)=	.000	TWH2(19)=	0.000	TWC1(19)=	0.000	TWC2(19)=	0.000
TWH1(20)=	0.000	TWH2(20)=	0.000	TWC1(20)=	0.000	TWC2(20)=	0.000
TWH1(21)=	0.000	TWH2(21)=	0.000	TWC1(21)=	0.000	TWC2(21)=	0.000
TWH1(22)=	0.000	TWH2(22)=	0.000	TWC1(22)=	0.000	TWC2(22)=	0.000
TWH1(23)=	0.000	TWH2(23)=	0.000	TWC1(23)=	0.000	TWC2(23)=	0.000
THC2(1)=	0.000	THW1(1)=	0.000	THW2(1)=	0.000		
THC2(2)=	0.000	THW1(2)=	0.000	THW2(2)=	0.000		
THC2(3)=	0.000	THW1(3)=	0.000	THW2(3)=	0.000		
THC2(4)=	0.000	THW1(4)=	0.000	THW2(4)=	0.000		
THC2(5)=	0.000	THW1(5)=	0.000	THW2(5)=	0.000		
THC2(6)=	0.000	THW1(6)=	0.000	THW2(6)=	0.000		
THC2(7)=	0.000	THW1(7)=	0.000	THW2(7)=	0.000		
THC2(8)=	0.000	THW1(8)=	0.000	THW2(8)=	0.000		
THC2(9)=	0.000	THW1(9)=	0.000	THW2(9)=	0.000		
THC2(10)=	0.000	THW1(10)=	117.809	THW2(10)=	0.000		
THC2(11)=	0.000	THW1(11)=	0.000	THW2(11)=	0.000		
THC2(12)=	0.000	THW1(12)=	0.000	THW2(12)=	0.000		
THC2(13)=	0.000	THW1(13)=	0.000	THW2(13)=	0.000		
THC2(14)=	0.000	THW1(14)=	0.000	THW2(14)=	0.000		
THC2(15)=	0.000	THW1(15)=	0.000	THW2(15)=	0.000		
THC2(16)=	0.000	THW1(16)=	0.000	THW2(16)=	0.000		
THC2(17)=	0.000	THW1(17)=	0.000	THW2(17)=	0.000		
THC2(18)=	0.000	THW1(18)=	0.000	THW2(18)=	0.000		
THC2(19)=	0.000	THW1(19)=	0.000	THW2(19)=	0.000		
THC2(20)=	0.000	THW1(20)=	0.000	THW2(20)=	0.000		
THC2(21)=	0.000	THW1(21)=	0.000	THW2(21)=	0.000		
THC2(22)=	0.000	THW1(22)=	0.000	THW2(22)=	0.000		
THC2(23)=	0.000	THW1(23)=	693.469	THW2(23)=	0.000		

THC1(12)=	0.000		
THC1(13)=	0.000		
THC1(14)=	0.000		
THC1(15)=	0.000		
THC1(16)=	0.000		
THC1(17)=	0.000		
THC1(18)=	0.000		
THC1(19)=	0.000		
THC1(20)=	0.000		
THC1(21)=	0.000		
THC1(22)=	0.000		
THC1(23)=	0.000		

WARTIME PRODUCTION CURVE

PRODUCTION(1)=	9.175
PRODUCTION(2)=	9.214
PRODUCTION(3)=	9.252
PRODUCTION(4)=	21.824
PRODUCTION(5)=	21.824
PRODUCTION(6)=	21.824
PRODUCTION(7)=	312.711
PRODUCTION(8)=	312.711
PRODUCTION(9)=	312.711
PRODUCTION(10)=	508.406
PRODUCTION(11)=	530.080
PRODUCTION(12)=	536.987
PRODUCTION(13)=	535.033
PRODUCTION(14)=	568.767
PRODUCTION(15)=	586.424
PRODUCTION(16)=	584.014
PRODUCTION(17)=	581.614
PRODUCTION(18)=	579.224
PRODUCTION(19)=	576.791
PRODUCTION(20)=	574.369
PRODUCTION(21)=	571.957
PRODUCTION(22)=	569.554

Figure 6. (contd)

```
PRODUCTION(23)=         .000
PRODUCTION(24)=      353.644

   TOTAL WARTIME PRODUCTION=   8709.167
```

Figure 6. (concluded)

REFERENCE

[1] Grotte, Jeffrey H., *Computer Program for Solving Separable Nonconvex Optimization Problems*, IDA P-1318, Institute for Defense Analyses, Arlington, Virginia, January 1978.

APPENDIX A

GLOSSARY OF INPUT PARAMETERS AND VARIABLES

GLOSSARY OF INPUT PARAMETERS

Name	Definition	Location of First Use
AMULT	The cost multiplier for Mobilization/War time steps in the interval [MA,MB]	71
BMULT	The cost multiplier for Mobilization/War time steps in the interval [MB,ISTEP]	71
BPBUDG	The user-supplied limit on the Build-up period capital purchase and ammunition production costs (undiscounted)	60
BPDEM	The demand for ammunition during each time step of the Build-up period	27
BUDG(t)	The user-supplied limit on the undiscounted costs of capital purchase and ammunition production applying to time step t	61
DC1	The fraction of type 1 cold stocks lost to deterioration during one time step	12
DC2	The fraction of type 2 cold stocks lost to deterioration during one time step	12
DD(t)	The domestic demand for ammunition during time step t	15
DH1	The fraction of type 1 hot stocks lost to deterioration during one time step	14
DH2	The fraction of type 2 hot stocks lost to deterioration during one time step	14
DS	The fraction of the domestic ammunition stockpile lost to deterioration during one time step	14
DSP	The fraction of the in-theater ammunition stockpile lost to deterioration during one time step	15
DW1	The fraction of type 1 warm stocks lost to deterioration during one time step	13
DW2	The fraction of type 2 warm stocks lost to deterioration during one time step	13

GLOSSARY OF INPUT PARAMETERS (contd)

EBUDG	The user-supplied limit on the Steady-state capital purchase and ammunition production costs (undiscounted)	60
ENDPRD	The level of ammunition production to be achieved during the final time step	57
ENDS	The amount of ammunition that must be held in the domestic stockpile during the final time step	57
ENDSP	The amount of ammunition that must be held in the in-theater stockpile during the final time step	57
FD(t)	The in-theater demand for ammunition during time step t	15
ISTEP	The number of time steps in the Mobilization/War period	47
KH1	The capital to output ratio for type 1 hot capital	15
KH2	The capital to output ratio for type 2 hot capital	15
KW1	The capital to output ratio for type 1 warm capital	14
KW2	The capital to output ratio for type 2 warm capital	15
LCH1	The number of time steps required to transfer type 1 capital from cold to hot stocks	14
LCH2	The number of time steps required to transfer type 2 capital from cold to hot stocks	14
LCW1	The number of time steps required to transfer type 1 capital from cold to warm stocks	14
LCW2	The number of time steps required to transfer type 2 capital from cold to warm stocks	14
LHC1	The number of time steps required to transfer type 1 capital from hot to cold stocks	13
LHC2	The number of time steps required to transfer type 2 capital from hot to cold stocks	13

LHW1	The number of time steps required to transfer type 1 capital from hot to warm stocks	14
LHW2	The number of time steps required to transfer type 2 capital from hot to warm stocks	15
LP1	The number of time steps from the time type 1 capital is purchased until it is delivered to cold stocks	12
LP2	The number of time steps from the time type 2 capital is purchased until it is delivered to cold stocks	12
LPIPE	The number of time steps required to transfer ammunition from the domestic to the in-theater stockpile	15
LWC1	The number of time steps required to transfer type 1 capital from warm to cold stocks	12
LWC2	The number of time steps required to transfer type 2 capital from warm to cold stocks	12
LWH1	The number of time steps required to transfer type 1 capital from warm to hot stocks	14
LWH2	The number of time steps required to transfer type 2 capital from warm to hot stocks	14
MA	The first time step of the Mobilization/War period at which cost multiplier AMULT is applied	71
MB	The first time step of the Mobilization/War period at which cost multiplier BMULT is applied	71
NLAG	The time delay in acquiring capital during the Build-up period	41
NPURCH	The number of time steps in the Build-up period	20
NSS	The number of time steps in the Steady-state period	41
OCOLD1	The amount of original type 1 cold capital	23
OCOLD2	The amount of original type 2 cold capital	23

GLOSSARY OF INPUT PARAMETERS (contd)

OMUN	The amount of original ammunition	27
OWARM1	The amount of original type 1 warm capital	26
OWARM2	The amount of original type 2 warm capital	26
R	The single time step discount factor for costs	18
RATIO	The user-specified ratio of total capital to total stockpile to be achieved during the end of the Build-up period	58
SLOPC1	The slope desired by the user for the type 1 cold capital purchase pattern	58
SLOPC2	The slope desired by the user for the type 2 cold capital purchase pattern	58
SLOPW1	The slope desired by the user for the linear component of the type 1 warm capital purchase pattern	58
SLOPW2	The slope desired by the user for the linear component of the type 2 warm capital purchase pattern	58
SSDEM	The demand for ammunition per time step during the Steady-state period	42
UBPIPE(t)	The maximum amount of ammunition that can be transferred from the domestic to the in-theater stockpile during time step t	57
UBPREP	The maximum amount of ammunition that can be prepositioned into the in-theater stockpile	57
UBSP(t)	The maximum amount of ammunition that can be held in the in-theater stockpile during time step t	57
VC1	The cost of maintaining one unit of type 1 capital in cold stocks for one time step	16
VC2	The cost of maintaining one unit of type 2 capital in cold stocks for one time step	16
VCH1	The cost of transferring one unit of type 1 capital from cold to hot stocks	17
VCH2	The cost of transferring one unit of type 2 capital from cold to hot stocks	17
VCW1	The cost of transferring one unit of type 1 capital from cold to warm stocks	17
VCW2	The cost of transferring one unit of type 2 capital from cold to warm stocks	17

VH1	The cost of maintaining one unit of type 1 capital in hot stocks for one time step	17
VH2	The cost of maintaining one unit of type 2 capital in hot stocks for one time step	17
VHC1	The cost of transferring one unit of type 1 capital from hot to cold stocks	18
VHC2	The cost of transferring one unit of type 2 capital from hot to cold stocks	18
VHW1	The cost of transferring one unit of type 1 capital from hot to warm stocks	18
VHW2	The cost of transferring one unit of type 2 capital from hot to warm stocks	18
VPC1	The cost of purchasing one unit of type 1 capital	16
VPC2	The cost of purchasing one unit of type 2 capital	16
VPH1	The cost of producing one unit of ammunition from type 1 hot stocks	17
VPH2	The cost of producing one unit of ammunition from type 2 hot stocks	17
VPIPE	The cost of transferring one unit of ammunition from the domestic to the in-theater stockpile	17
VPREP	The cost of prepositioning one unit of ammunition in the in-theater stockpile	46
VPW1	The cost of producing one unit of ammunition from type 1 warm stocks	17
VPW2	The cost of producing one unit of ammunition from type 2 warm stocks	17
VS	The cost of maintaining one unit of ammunition in the domestic stockpile for one time step	17
VSP	The cost of maintaining one unit of ammunition in the in-theater stockpile for one time step	17
VSPALV	The cost of holding one unit of ammunition in the in-theater stockpile during the final time step of the Mobilization/War period (if negative, this represents salvage value)	53

VSSALV	The cost of holding one unit of ammunition in the domestic stockpile during the final time step of the Mobilization/War period (if negative, this represents salvage value)	53
VW1	The cost of maintaining one unit of type 1 capital in warm stock for one time step	16
VW2	The cost of maintaining one unit of type 2 capital in warm stock for one time step	16
VWC1	The cost of transferring one unit of type 1 capital from warm to cold stocks	17
VWC2	The cost of transferring one unit of type 2 capital from warm to cold stocks	18
VWH1	The cost of transferring one unit of type 1 capital from warm to hot stocks	17
VWH2	The cost of transferring one unit of type 2 capital from warm to hot stocks	17

GLOSSARY OF MODEL VARIABLES

Name	Definition	Location of First Use
BC1	The amount of type 1 cold capital purchased at time step t=1	22
BC2	The amount of type 2 cold capital purchased at time step t=1	22
BW1	The amount of type 1 warm capital purchased during time step 1 as part of the linear portion of the purchase pattern	25
BW2	The amount of type 2 warm capital purchased during time step 1 as part of the linear portion of the purchase pattern	25
C1(t)	The amount of type 1 cold capital stocks held during time step t	10
C2(t)	The amount of type 2 cold capital stocks held during time step t	10
EC1	The amount of type 1 cold capital held during the Steady-state period	42
EC2	The amount of type 2 cold capital held during the Steady-state period	42
EPREP	The amount of ammunition explicitly prepositioned into the in-theater stockpile during the Steady-state period	43
ES	The total amount of ammunition held in stockpiles during the Steady-state period	42
EW1	The amount of type 1 warm capital held during the Steady-state period	42
EW2	The amount of type 2 warm capital held during the Steady-state period	42
H1(t)	The amount of type 1 hot capital stocks held during time step t	10
H2(t)	The amount of type 2 hot capital stocks held during time step t	10

GLOSSARY OF MODEL VARIABLES (contd)

IBW1	The amount of type 1 warm capital purchased during time step 1 in addition to BW1	26
IBW2	The amount of type 2 warm capital purchased during time step 1 in addition to BW2	26
PIPE(t)	The amount of ammunition transferred from the domestic to the in-theater stockpile beginning during time step t	11
S(t)	The amount of ammunition held in the domestic stockpile during time step t	11
SLPNC1	The negative component of the slope of the type 1 cold capital purchase pattern	22
SLPNC2	The negative component of the slope of the type 2 cold capital purchase pattern	22
SLPNW1	The negative component of the slope of the linear portion of the type 1 warm capital purchase pattern	26
SLPNW2	The negative component of the slope of the linear portion of the type 2 warm capital purchase pattern	26
SLPPC1	The positive component of the slope of the type 1 cold capital purchase pattern	22
SLPPC2	The positive component of the slope of the type 2 cold capital purchase pattern	22
SLPPW1	The positive component of the slope of the linear portion of the type 1 warm capital purchase pattern	26
SLPPW2	The positive component of the slope of the linear portion of the type 2 warm capital purchase pattern.	26
SP(t)	The amount of ammunition held in the in-theater stockpile during time step t	11
TCH1(t)	The amount of type 1 capital transferred from cold to hot stocks beginning during time step t	11
TCH2(t)	The amount of type 2 capital transferred from cold to hot stocks beginning during time step t	11
TCW1(t)	The amount of type 1 capital transferred from cold to warm stocks beginning during time step t	11

GLOSSARY OF MODEL VARIABLES (concluded)

TCW2(t)	The amount of type 2 capital transferred from cold to warm stocks beginning during time step t	11
THC1(t)	The amount of type 1 capital transferred from hot to cold stocks beginning during time step t	11
THC2(t)	The amount of type 2 capital transferred from hot to cold stocks beginning during time step t	11
THW1(t)	The amount of type 1 capital transferred from hot to warm stocks beginning during time step t	11
THW2(t)	The amount of type 2 capital transferred from hot to warm stocks beginning during time step t	11
TWC1(t)	The amount of type 1 capital transferred from warm to cold stocks beginning during time step t	11
TWC2(t)	The amount of type 2 capital transferred from warm to cold stocks beginning during time step t	11
TWH1(t)	The amount of type 1 capital transferred from warm to hot stocks beginning during time step t	11
TWH2(t)	The amount of type 2 capital transferred from warm to hot stocks beginning during time step t	11
W1(t)	The amount of type 1 warm capital stocks held during time step t	10
W2(t)	The amount of type 2 warm capital stocks held during time step t	10

APPENDIX B

STOCKPILE/PRODUCTION BASE MODEL

FORTRAN LISTING

```
      PROGRAM MOGG(INPUT,OUTPUT,TAPE6=OUTPUT)
C     *****MAXVAR,THE MAXIMUM NUMBER OF ORIGINAL VARIABLES, DIMENSIONS
C          KLO,KRO,KL,KR,XCODED,XBEST,VARNAM
C     *****MAXCUT, THE MAXIMUM NUMBER OF INTERNAL VARIABLES DIMENSIONS
C          W,CUTS
C     *****LSTMAX, THE MAXIMUM LIST SIZE DIMENSIONS ZLSTNO,ZLSTRA
C           LSTKL, LSTKR,ZLSLB ,IBRVR,FLAG
C     *****MAXROW=MAXIMUM NUMBER OF ROWS (INC. OBJECTIVE FUNCTION),
C          DIMENSIONS ICHK
C     *****MAXA DIMENSIONS A,IA
      REAL KW1,KW2,KH1,KH2
      COMMON        KLO(840),KRO(840),KL(840),KR(840),XCODED(840),XBEST
     1(840),W(840),CUTS(840),ZLSTNO(5),ZLSTRA(5),LSTKL(5),LSTKR(5),
     2ZLSLB(5),IBRVR(5),FLAG(5),KBL(3),KBR(3),VARNAM(1),PROBNA(1),
     3MAXVAR,MAXCUT,LSTMAX,MAXROW,MAXA,NMROWS,NUMVAR,ICHK(430),VAL,LFLG,
     4ISTEP,LWH1,LWH2,KW1,KW2,KH1,KH2
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVFRQ,IOBJ,IROWP,ITCH,ITCHA,ITCNT,ITRFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NFLEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QEC,QBL,QPL,QMI,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUEG(36),DD(36),FD(36),UBSP(36),UBPIPE(36)
      DATA IOBJ,INVFRQ,ITRFRQ/1,50,2000/
      DATA ZTOLZE,ZTOLPV,ZTCOST/1.E-10,1.E-5,1.E-6/
      DATA NRMAX,NTMAX,NEMAX/430,2000,5700/
      DATA QRO,QMA,QBA,QFI,QEC,QBL,QPL,QMI/4HROW ,4HMATR,4HBASI,
     1  4HFIRS,4HECF ,4H    ,4H + ,4H - /
      DATA QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ/4HA   ,4HB   ,
     1  4HC   ,4HE   ,4HF   ,4HG   ,4HH   ,4HI   ,4HL   ,4HM   ,4HN   ,
     2  4HO   ,4HR   ,4HU   ,4H Z  /
      DATA BURTOL,FEASTL,DIFFTO,RONTOL/1.E-3,1.E-3,1.E-3,1.E-3/
      DATA CUTTOL/1.E-8/
      MAXVAR=840
      MAXCUT=840
      LSTMAX=5
      MAXROW=430
      MAXA=3700
      WMM=5HMANU.
      BUB=1.E70
C     *****THIS SECTION READS IN DATA
 5    FORMAT(61H1PROGRAM MOGG--FINDS GLOBAL SOLUTIONS TO APPROXIMATE PRO
     1BLEMS)
      READ 7
    7 FORMAT(50H                                                  )
      READ 10,IXPRIN,K1,K2,K3,K4,K5,KC1,KC2,KC3,KC4
10    FORMAT(16I5)
      READ 10,KLAG,NPURCH,NSS,ISTEP
C     PUT INPUT SECTION HERE
      PRINT 20010
20010 FORMAT(1H1,*IDA STOCKPILE/PRODUCTION BASE MODEL*)
      PRINT 7
      IF(KC1.NE.0)PRINT 20020
20020 FORMAT(1H0,*FINAL PERIOD STOCKPILES AND PRODUCTION HAVE BEEN SET*)
      IF(KC2.NE.0)PRINT 20030
```

```
20030 FORMAT(1H0,*BUY PERIOD SLOPES HAVE BEEN SET*)
      IF(KC3.NE.0)PRINT 20040
20040 FORMAT(1H0,*CAPITAL STOCK TO STOCKPILE RATIO HAS BEEN SET*)
      IF(KC4.EQ.1)PRINT 20042
      IF(KC4.EQ.2)PRINT 20044
20042 FORMAT(1H0,*INITIAL WARM CAPITAL PURCHASES ELIMINATED*)
20044 FORMAT(1H0,*LEVEL WARM CAPITAL PURCHASES ELIMINATED*)
      PRINT 20015,NLAG,NPURCH,NSS,ISTEP
20015 FORMAT(1H0,*NLAG= *I5,6X*NPURCH= *I5,6X*NSS= *I5,6X*ISTEP= *I5)
      PRINT 20050
20050 FORMAT(1H0,*COSTS *,50(1H*))
       READ 20175,VC1,VC2,VW1,VW2,VPW1,VPW2,VH1,VH2
      READ 20175,VPH1,VPH2,VPC1,VPC2,VCW1,VCW2,VCH1,VCH2
      READ20175,VWH1,VWH2,VWC1,VWC2,VHC1,VHC2,VHW1,VHW2
      READ 20065,VPIPE,VS,VSP,VSSALV,VSPALV,VBSALV,VPREP,R
20065 FORMAT(8F10.3)
      READ 20060,MA,MB,AMULT,BMULT
20060 FORMAT(2I5,2F10.3)
      PRINT 20070
20070 FORMAT(1H0,*VC1*12X*VC2*12X*VW1*12X*VW2*12X*VPW1*11X*VPW2*11X*VH1*
     112X*VH2*)
      PRINT 20080,VC1,VC2,VW1,VW2,VPW1,VPW2,VH1,VH2
20080 FORMAT(1H ,8(F12.4,3X))
      PRINT 20090
20090 FORMAT(1H0,*VPH1*11X*VPH2*11X*VPC1*11X*VPC2*11X*VCW1*11X*VCW2*11X*
     1VCH1*11X*VCH2*)
      PRINT 20100,VPH1,VPH2,VPC1,VPC2,VCW1,VCW2,VCH1,VCH2
20100 FORMAT(1H ,8(F12.4,3X))
      PRINT 20110
20110 FORMAT(1H0,*VWH1*11X*VWH2*11X*VWC1*11X*VWC2*11X*VHC1*11X*VHC2*11X*
     1VHW1*11X*VHW2*)
      PRINT 20120,VWH1,VWH2,VWC1,VWC2,VHC1,VHC2,VHW1,VHW2
20120 FORMAT(1H ,8(F12.4,3X))
      PRINT 20130
20130 FORMAT(1H0,*VPIPE*10X*VS*13X*VSP*12X*VSSALV*9X*VSPALV*9X*VBSALV*9X
     1*VPREP*10X*R*)
      PRINT 20140,VPIPE,VS,VSP,VSSALV,VSPALV,VBSALV,VPREP,R
20140 FORMAT(1H ,8(F12.4,3X))
      PRINT 20150
20150 FORMAT(1H0,*MA*13X*MB*13X*AMULT*10X*BMULT*)
      PRINT 20160,MA,MB,AMULT,BMULT
20160 FORMAT(1H ,I5,10X,I5,10X,2(F12.4,3X))
C
      PRINT 20170
20170 FORMAT(1H-,*CAPITAL/OUTPUT RATIOS *,33(1H*))
      READ 20175,KW1,KW2,KH1,KH2
20175 FORMAT(8F10.4)
      PRINT 20180
20180 FORMAT(1H0,*KW1*12X*KW2*12X*KH1*12X*KH2*)
      PRINT 20190,KW1,KW2,KH1,KH2
20190 FORMAT(1H ,4(F12.3,3X))
      PRINT 20200
20200 FORMAT(1H-,*DETERIORATION RATES *,36(1H*))
      READ 20210,DC1,DC2,DW1,DW2,DH1,DH2,DS,DSP
20210 FORMAT(8F10.4)
      PRINT 20220
20220 FORMAT(1H0,*DC1*12X*DC2*12X*DW1*12X*DW2*12X*DH1*12X*DH2*12X*DS*
     113X*DSP*)
```

```
      PRINT 20230,DC1,DC2,DW1,DW2,DH1,DH2,DS,USP
20230 FORMAT(1H ,8(F12.3,3X))
      PRINT 20240
20240 FORMAT(1H-,*TIME LAGS *,46(1H*))
      READ 20250,LP1,LP2,LCW1,LCW2,LCH1,LCH2,LWH1,LWH2,LHC1,LHC2,LHW1,
     1LHW2,LWC1,LWC2,LPIPE
20250 FORMAT(16I5)
      PRINT 20260
20260 FORMAT(1H0,*LP1*4X*LP2*4X*LCW1*3X*LCW2*3X*LCH1*3X*LCH2*3X*LWH1*3X*
     1LWH2*3X*LHC1*3X*LHC2*3X*LHW1*3X*LHW2*3X*LWC1*3X*LWC2*3X*LPIPE*)
      PRINT 20270,LP1,LP2,LCW1,LCW2,LCH1,LCH2,LWH1,LWH2,LHC1,LHC2,LHW1,
     1LHW2,LWC1,LWC2,LPIPE
20270 FORMAT(1H ,15(I3,4X))
C
      PRINT 20280
20280 FORMAT(1H-,*ORIGINALS *,46(1H*))
      READ 20290,OMUN,OCOLD1,OCOLD2,OWARM1,OWARM2
20290 FORMAT(8F10.4)
      PRINT 20300
20300 FORMAT(1H0,*OMUN*11X*OCOLD1*9X*OCOLD2*9X*OWARM1*9X*OWARM2*)
      PRINT 20310,OMUN,OCOLD1,OCOLD2,OWARM1,OWARM2
20310 FORMAT(1H ,8(F12.4,3X))
      OMUNX=(OWARM1/KW1)*NLAG+(OWARM2/KW2)*NLAG
      PRINT 20315,OMUNX
20315 FORMAT(1H0,10X,*PRODUCTION DURING NLAG = *,F10.4)
      OMUN=OMUN+OMUNX
      PRINT 20316,OMUN
20316 FORMAT(1H0,10X,*INVENTORY AFTER NLAG = *,F10.4)
      PRINT 20320
20320 FORMAT(1H-,*BUDGETS *,48(1H*))
      READ 20330,BPBUDG,EBUDG
      READ 20330,(BUDG(I),I=1,ISTEP)
20330 FORMAT(8F10.4)
      PRINT 20340,BPBUDG
20340 FORMAT(1H0,*BPBUDG= *,F12.3)
      PRINT 20350,EBUDG
20350 FORMAT(1H0,*EBUDG= *,F12.3)
      PRINT 20360,(BUDG(I),I=1,ISTEP)
20360 FORMAT(1H0,*BUDG= *,8(F12.3,3X))
      PRINT 20370
20370 FORMAT(1H-,*DEMANDS *,48(1H*))
      I=ISTEP
      READ 20380,BPDEM,SSDEM
      READ 20380,(DD(J),J=1,I)
      READ 20380,(FD(J),J=1,I)
20380 FORMAT(8F10.4)
      PRINT 20390,BPDEM
20390 FORMAT(1H0,*BPDEM= *,F12.4)
      PRINT 20400,SSDEM
20400 FORMAT(1H0,*SSDEM= *,F12.4)
      PRINT 20410,(DD(J),J=1,I)
20410 FORMAT(1H0,*DD= *,8(F12.3,3X))
      PRINT 20420,(FD(J),J=1,I)
20420 FORMAT(1H0,*FD= *,8(F12.3,3X))
      PRINT 20430
20430 FORMAT(1H-,*UPPER BOUNDS *,43(1H*))
      I=I-1
      READ 20440,UBPREP
```

```
      READ 20440,(UBSP(J),J=1,ISTEP)
      READ 20440,(UBPIPE(J),J=1,I)
20440 FORMAT(8F10.4)
      PRINT 20450,UBPPEP
20450 FORMAT(1H0,*UBPPEP= *,F12.4)
      PRINT 20460,(UBSP(J),J=1,ISTEP)
20460 FORMAT(1H0,*UBSP= *9(F12.3,3X))
      PRINT 20470,(UBPIPE(J),J=1,I)
20470 FORMAT(1H0,*UBPIPE= *,9(F12.3,3X))
      PRINT 20480
20480 FORMAT(1H-,*OPTIONAL INFORMATION *25(1H*))
      IF(KC1.EQ.0)GO TO 21010
      READ 20490,ENDS,ENDSP,ENDPRD
20490 FORMAT(8F10.4)
      PRINT 20500,ENDS,ENDSP,ENDPRD
20500 FORMAT(1H0,*ENDS=*F12.4,2X*ENDSP= *F12.4,2X*ENDPRD= *F12.4)
21010 IF(KC2.EQ.0)GO TO 21020
      READ 20510,SLOPC1,SLOPC2,SLOPW1,SLOPW2
20510 FORMAT(8F10.4)
      PRINT 20520,SLOPC1,SLOPC2,SLOPW1,SLOPW2
20520 FORMAT(1H0,*SLOPC1= *F12.4,2X*SLOPC2= *F12.4,2X*SLOPW1= *F12.4,2X
     1*SLOPW2= *F12.4)
21020 IF(KC3.EQ.0)GO TO 21030
      READ 20530,RATIO
20530 FORMAT(8F10.4)
      PRINT 20540,RATIO
20540 FORMAT(1H0,*RATIO= *F12.4)
21030 CONTINUE
      ZZ1=0.
      ZY1=0.
      LU=NLAG+NPURCH
      IF (LU.LT.1) GO TO 40005
      LL=1
      DO 40003 I=LL,LU
      ZZ1=ZZ1+((1.-DW1)**(I-1))/((1.+R)**I)
40003 ZY1=ZY1+((1.-DW2)**(I-1))/((1.+R)**I)
40005 CONTINUE
      ZZ2=0.
      ZY2=0.
      IF (LU.LT.1) GO TO 40010
      LL=1
      DO 40007II=LL,LU
      ZZ2=ZZ2+FUNCT5(DW1,DS,II)/((1.+R)**II)
40007 ZY2=ZY2+FUNCT5(DW2,DS,II)/((1.+R)**II)
40010 CONTINUE
      ZZ3=1./((1.+R)**(1-LCW1))
      ZY3=1./((1.+R)**(1-LCW2))
      ZZ4=1./((1.+R)**(1-LCW1-LP1))
      ZY4=1./((1.+R)**(1-LCW2-LP2))
      ZZ5=FUNCT5(DW1,DS,NPURCH)
      ZY5=FUNCT5(DW2,DS,NPURCH)
      ZZZ=(VW1+VPW1/KW1)*ZZ1+VS*ZZ2/KW1
      ZZZ=ZZZ*CWARM1
      ZZY=(VW2+VPW2/KW2)*ZY1+VS*ZY2/KW2
      ZZY=ZZY*CWARM2
      TCOSTS=ZZZ+ZZY
      PRINT 40015,ZZZ,ZZY
40015 FORMAT(1H-,*PRODUCTION COSTS FROM ORIGINAL WARM1= *F12.3*  PRODUCT
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```
     ION COSTS FROM ORIGINAL WARM2= *F12.3)
      Z1=FUNCT1(DW1,NPURCH)
      Z2=FUNCT2(DW1,NPURCH)
      Z3=FUNCT1(DW2,NPURCH)
      Z4=FUNCT2(DW2,NPURCH)
      Z5=FUNCT1(DC1,NPURCH)
      Z6=FUNCT2(DC1,NPURCH)
      Z7=FUNCT1(DC2,NPURCH)
      Z8=FUNCT2(DC2,NPURCH)
      Z0=0.
      DO 21040 I=1,NPURCH
21040 Z0=Z0+FUNCT1(DW1,I)*((1.-DS)**(NPURCH-I))
      Z0=Z0/KW1
      Z9=0.
      DO 21050 I=1,NPURCH
21050 Z9=Z9+FUNCT1(DW2,I)*((1.-DS)**(NPURCH-I))
      Z9=Z9/KW2
      Z10=0.
      DO 21060 I=1,NPURCH
21060 Z10=Z10+FUNCT2(DW1,I)*((1.-DS)**(NPURCH-I))
      Z10=Z10/KW1
      Z11=0.
      DO 21070 I=1,NPURCH
21070 Z11=Z11+FUNCT2(DW2,I)*((1.-DS)**(NPURCH-I))
      Z11=Z11/KW2
      Z12=FUNCT1(DS,NPURCH)
      Z13=0.
      DO 21080 I=1,NPURCH
21080 Z13=Z13+(1.+R)**(LP1-I)
      Z13=Z13*VPC1
      DO 21090 I=1,NPURCH

21090 Z13=Z13+VC1*FUNCT1(DC1,I)/((1.+R)**I)
      Z14=0.
      DO 21100 I=1,NPURCH
21100 Z14=Z14+(VPC1*(FLOAT(I)-1.)/((1.+R)**(I-LP1)))+(VC1*FUNCT2(DC1,I)/
     1((1.+R)**I))
      Z15=0.
      DO 21110 I=1,NPURCH
21110 Z15=Z15+(VPC2/((1.+R)**(I-LP2)))+(VC2*FUNCT1(DC2,I)/((1.+R)**I))
      Z16=0.
      DO 21120 I=1,NPURCH
21120 Z16=Z16+(VPC2*(FLOAT(I)-1.)/((1.+R)**(I-LP2)))+(VC2*FUNCT2(DC2,I)/
     1((1.+R)**I))
      Z17=0.
      DO 21130 I=1,NPURCH
21130 Z17=Z17+(VW1*FUNCT1(DW1,I)/((1.+R)**I))+((VPW1/KW1)*FUNCT1(DW1,I)/
     1((1.+R)**I))+((VS/KW1)*FUNCT3(DS,DW1,I)/((1.+R)**I))+(VCW1/((1.+R)
     2**(I-LCW1)))+(VPC1/((1.+R)**(I-LCW1-LP1)))
      Z19=0.
      DO 21140 I=1,NPURCH
21140 Z19=Z19+(VW2*FUNCT1(DW2,I)/((1.+R)**I))+((VPW2/KW2)*FUNCT1(DW2,I)/
     1((1.+R)**I))+((VS/KW2)*FUNCT3(DS,DW2,I)/((1.+R)**I))+(VCW2/((1.+R)
     2**(I-LCW2)))+(VPC2/((1.+R)**(I-LCW2-LP2)))
      Z18=0.
      DO 21150 I=1,NPURCH
21150 Z18=Z18+(VW1*FUNCT2(DW1,I)/((1.+R)**I))+((VPW1/KW1)*FUNCT2(DW1,I)/
     1((1.+R)**I))+((VS/KW1)*FUNCT4(DS,DW1,I)/((1.+R)**I))+(VCW1*(FLOAT(
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     2I)-1.)/((1.+R)**(I-LCW1)))+(VPC1*(FLOAT(I)-1.)/((1.+R)**(I-LCW1-
     3LP1)))
      Z20=0.
      DO 21160 I=1,NPURCH
21160 Z20=Z20+(VW2*FUNCT2(DW2,I)/((1.+R)**I))+((VPW2/KW2)*FUNCT2(DW2,I)/
     1((1.+R)**I))+((VS/KW2)*FUNCT4(DS,DW2,I)/((1.+R)**I))+(VCW2*(FLOAT(
     2I)-1.)/((1.+R)**(I-LCW2)))+(VPC2*(FLOAT(I)-1.)/((1.+R)**(I-LCW2-
     3LP2)))
      Z21=0.
      Z22=0.
      Z23=0.
      Z24=0.
      Z25=0.
      Z34=0.
      Z35=0.
      Z36=0.
      Z37=0.
      IF(NSS.EQ.0)GO TO 22000
      DO 21170 I=1,NSS
      Z21=Z21+(VPC1*DC1/((1.+R)**(I-LP1+NPURCH)))+(VC1/((1.+R)**(I+NPURC
     1H)))
      Z22=Z22+(VPC2*DC2/((1.+R)**(I-LP2+NPURCH)))+(VC2/((1.+R)**(I+NPURC
     1H)))
      Z23=Z23+((VPW1/KW1)/((1.+R)**(I+NPURCH)))+(VW1/((1.+R)**(I+NPURCH)
     1))+(VCW1*DW1/((1.+R)**(I-LCW1+NPURCH)))+(VPC1*DW1/((1.+R)**(I-LCW1
     2-LP1+NPURCH)))
      Z24=Z24+((VW2+VPW2/KW2)/((1.+R)**(I+NPURCH)))+(VCW2*DW2/((1.+R)**(
     1I-LCW2+NPURCH)))+(VPC2*DW2/((1.+R)**(I-LCW2-LP2+NPURCH)))
21170 Z25=Z25+VS/((1.+R)**(I+NPURCH))
      Z34=VPC1*DC1*FLOAT(NSS)
      Z35=VPC2*DC2*FLOAT(NSS)
      Z36=(VPC1*DW1+VPW1/KW1)*FLOAT(NSS)
      Z37=(VPC2*DW2+VPW2/KW2)*FLOAT(NSS)
22000 CONTINUE
      Z26=0.
      Z27=0.
      Z28=0.
      Z29=0.
      Z30=0.
      Z31=0.
      Z32=0.
      Z33=0.
      DO 22010 I=1,NPURCH
      Z30=Z30+VPC1*(FLOAT(I)-1.)
      Z31=Z31+VPC2*(FLOAT(I)-1.)
      Z28=Z28+(VPW1/KW1)*FUNCT1(DW1,I)
      Z29=Z29+(VPW2/KW2)*FUNCT1(DW2,I)
      Z32=Z32+(VPW1/KW1)*FUNCT2(DW1,I)+VPC1*(FLOAT(I)-1.)
22010 Z33=Z33+(VPW2/KW2)*FUNCT2(DW2,I)+VPC2*(FLOAT(I)-1.)
      Z26=VPC1*FLOAT(NPURCH)
      Z27=VPC2*FLOAT(NPURCH)
      Z28=Z28+VPC1*FLOAT(NPURCH)
      Z29=Z29+VPC2*FLOAT(NPURCH)
      KRUB=0
   12 FORMAT(F10.6)
      PRINT 15
   15 FORMAT(1H1,*PROBLEM INFORMATION*,/)
      NMROWS=15+11*ISTEP
```

```
      IF(KC1.EQ.1)NMROWS=NMROWS+3
      IF(KC2.EQ.1)NMROWS=NMROWS+4
      IF(KC3.EQ.1)NMROWS=NMROWS+1
      IF(NSS.GT.0)NMROWS=NMROWS+1
      IF(KC4.GE.1)NMROWS=NMROWS+1
      NUMVAR=5+23*ISTEP
      NUMVAR=NUMVAR+2
      MAXLP=5

      PRINT 20,NMROWS
20    FORMAT(1H ,20X,I10,4HROWS)
      PRINT 25,NUMVAR
25    FORMAT(1H ,20X,I10,9HVARIABLES)
      PRINT 30,MAXLP
30    FORMAT(1H ,20X,I10,5X,26HLP PROBLEMS WILL BE SOLVED)
      IF(KBUB.NE.0)PRINT 35,BUB
35    FORMAT(1H ,20X,22HUSER-SUPPLIED BUB IS--,F10.6)
      IF(IXPRIN.NE.0)PRINT40
40    FORMAT(1H ,20X,59HTHE USER REQUESTS THAT ALL FEASIBLE POINTS FOUND
     1 BE PRINTED)
      IF(K1.NE.0)PRINT45
45    FORMAT(1H ,20X,50HTHE USER REQUESTS THAT ALL LP SOLUTIONS BE PRINT
     1ED)
      IF(K2.NE.0)PRINT 50
50    FORMAT(1H ,20X,44HTHE USER REQUESTS THAT THE MATRIX BE PRINTED)
      IF(K3.NE.0)PRINT 51
51    FORMAT(1H ,20X,43HTHE USER REQUESTS LP INFORMATION BE PRINTED)
      IF(K4.NE.0)PRINT 52
52    FORMAT(1H ,20X,66HTHE USER REQUESTS THAT THE ENTIRE LIST BE PRINTE
     1D AFTER EACH STAGE)
      IF(K5.NE.0)PRINT 53
53    FORMAT(1H ,20X,43HTHE USER REQUESTS THAT THE MATRIX BE SCALED)
      ISTYPE(1)=0
      ISTYPE(2)=1
      ISTYPE(3)=1
      IF(NSS.EQ.0)ISTYPE(2)=-1
      IF(NSS.EQ.0)ISTYPE(3)=-1
      ISTYPE(4)=-1
      ISTYPE(5)=-1
      ISTYPE(6)=-1
      ISTYPE(7)=1
      ISTYPE(8)=1
      ISTYPE(9)=1
      ISTYPE(10)=1
      LL=11
      LU=           10+8*ISTEP
      DO 10010 I=LL,LU
10010 ISTYPE(I)=-1
      LL=11+8*ISTEP
      LU=15+11*ISTEP
      DO 10020 I=LL,LU
10020 ISTYPE(I)=1
      IF(KC1.EQ.0)GO TO 10030
      LU=LU+1
      ISTYPE(LU)=1
      LU=LU+1
      ISTYPE(LU)=1
      LU=LU+1
```

```
      ISTYPE(LU)=1
10030 IF(KC2.EQ.0)GO TO 10040
      DO 10035 I=1,4
      LU=LU+1
10035 ISTYPE(LU)=-1
10040 IF(KC3.EQ.0)GO TO 10050
      LU=LU+1
      ISTYPE(LU)=-1
10050 IF(NSS.EQ.0)GO TO 10060
      LU=LU+1
      ISTYPE(LU)=-1
C     END OF SETTING ROW TYPE
10060 IF(KC4.EQ.0)GO TO 10063
      LU=LU+1
      ISTYPE(LU)=-1
10063 CONTINUE
      PRINT60
 60   FORMAT(1H0,10HROW TYPE--)
      PRINT 65,(ISTYPE(I),I=1,NMROWS)
 65   FORMAT(1H , 40I2)
      DO 10070 I=1,NMROWS
C     VARIABLE CARDS
10070 ICHK(I)=0
      PRINT 75
 75   FORMAT(1H0,17HCONVEXITY FLAGS--,/)
      PRINT 80,(ICHK(I),I=1,NMROWS)
 80   FORMAT(1H ,80I1)
C     *****NOW SET UP CUTS VECTOR, KLO, AND KRO--
      PRINT 90
 90   FORMAT(1H0,27HVARIABLE CARDS REPRODUCED--,/)
           DO 100 I=1,NUMVAR
      NOVAR=1
      NOINC=0
      WORD=5HALTO.
C     RHS CARDS
      IF(NOVAR.NE.I)CALL ERR(1)
           IF(NOINC.EQ.0)115,120
 115       IF(I.EQ.1)116,117
 116       KLO(I)=1
           KRO(I)=1
           GO TO 100
 117       IX=KRO(I-1)+1
      IF(IX.GT.MAXCUT)CALL ERR(2)
           KLO(I)=KRO(I-1)+1
           KRO(I)=KLO(I)
           GO TO 100
 120       IF(I.EQ.1)122,124
 122       KLO(I)=1
           GO TO 126
 124       IX=KRO(I-1)+1
      IF(IX.GT.MAXCUT)CALL ERR(2)
           KLO(I)=KRO(I-1)+1
 126  IF((KLO(I)+NOINC).GT.MAXCUT)CALL ERR(2)
           KRO(I)=KLO(I)+NOINC
           IF(WORD.EQ.WMM)GO TO 145
           I1=KLO(I)
           I2=KRO(I)
           READ 130,CUTS(I1),CUTS(I2)
```

```
 130       FORMAT(2F10.6)
           PRINT 135,CUTS(I1),CUTS(I2)
 135       FORMAT(1H ,2G10.4)
           IF((I2-I1).EQ.1)GO TO 100
                IX=I2-I1-1
                DO 140 J=1,IX
 140            CUTS(I1+J)=CUTS(I1)+J*(CUTS(I2)-CUTS(I1))/NOINC
           GO TO 100
 145       CONTINUE
C     *****HERE IF WE ARE TO READ IN CUTS MANUALLY
           IW=KLO(I)
           IZ=KRO(I)
           READ 150,(CUTS(J),J=IW,IZ)
 150       FORMAT(8F10.6)
           PRINT 155,(CUTS(J),J=IW,IZ)
 155  FORMAT(1H ,8G12.4)
 100       CONTINUE
C     *****WE HAVE COMPLETED READING BOUNDS AND CUTS
      PRINT 160
 160  FORMAT(1H0,24HRHS CARD(S) REPRODUCED--,/)
      B(1)=0.
      B(2)=OWARM1*((1.-DW1)**(NPURCH-1))
      B(3)=OWARM2*((1.-DW2)**(NPURCH-1))
      B(4)=OCOLD1*((1.-DC1)**(NPURCH-1))
      B(4)=B(4)+B(2)
      B(5)=OCOLD2*((1.-DC2)**(NPURCH-1))
      B(5)=B(5)+B(3)
      B(6)=BPDEM*Z12-OMUN*((1.-US)**(NPURCH-1))
      B(6)=B(6)-(ZZ5*OWARM1/KW1)-(ZY5*OWARM2/KW2)
      B(7)=-BPDEM
      B(7)=B(7)+OWARM1/KW1+OWARM2/KW2
      B(8)=-BPDEM
      B(8)=B(8)+B(2)/KW1+B(3)/KW2
      B(9)=0
      B(10)=UPPREP
      LL=11
      LU=10+6*ISTEP
      DO 10080 I=LL,LU
10080 B(I)=0.
      LL=11+6*ISTEP
      LU=10+7*ISTEP
      DO 10090 I=LL,LU
      II=I-LL+1
10090 B(I)=DD(II)
      LL=LU+1
      LU=10+8*ISTEP
      DO 10100 I=LL,LU
      II=I-LL+1
10100   B(I)=FC(II)
      LL=LU+1
      LU=10+9*ISTEP
      DO 10110 I=LL,LU
      II=I-LL+1
10110 B(I)=UHSP(II)
      LL=LU+1
      LU=9+10*ISTEP
      DO 10120 I=LL,LU
      II=I-LL+1
```

```
10120 B(I)=UPRIPE(II)
      LL=LU+1
      LU=LU+ISTEP
      DO 10140 I=LL,LU
      II=I-LL+1
10140 B(I)=BUDG(II)
      LU=LU+1
      B(LU)=BPBUDG
      LU=LU+1
      B(LU)=FBLDG
      LU=LU+1
      B(LU)=0.
      LU=LU+1
      B(LU)=0.
      LU=LU+1
      B(LU)=0.
      LU=LU+1
      B(LU)=0.
      IF(KC1.EQ.0)GO TO 10150
      LU=LU+1
      B(LU)=-ENDS
      LU=LU+1
      B(LU)=-ENDSP
      LU=LU+1
      B(LU)=-ENDPRD
10150 IF(KC2.EQ.0) GO TO 10160
      LU=LU+1
      B(LU)=SLCPC1
      LU=LU+1
      B(LU)=SLCPC2
      LU=LU+1
      B(LU)=SLCPW1
      LU=LU+1
      B(LU)=SLCPW2
10160 IF(KC3.EQ.0)GO TO 10170
      LU=LU+1
      B(LU)=0.
10170 IF(NSS.EQ.0)GO TO 10180
      LU=LU+1
      B(LU)=SSCEM
10180 IF(KC4.EQ.0)GO TO 10185
      LU=LU+1
      B(LU)=0.
10185 CONTINUE
C     END OF RHS
C     FILL IN COLUMNS
      PRINT 170,(B(I),I=1,NMROWS)
 170  FORMAT(1H ,8G12.4)
C
C        SET NROW,B(.),ISTYPE(.)
C
      NROW=NMROWS
      DO 9000 JJ=1,NUMVAR
      J1=KLO(JJ)
      J2=KPO(JJ)
      IF (J1.EQ.J2)  GO TO 9000
      NROW=NROW+1
 9000 CONTINUE
```

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C
      I1=NMROWS+1
      DO 9010 I=I1,NROW
      B(I)=1.
      ISTYPE(I)=-1
 9010 CONTINUE
C
C .       ADD SLACKS TO COEFFICIENT MATRIX
C
      NELEM=0
      NCOL=0
      DO 9100 I=1,NROW
      NELEM=NELEM+1
      NCOL=NCOL+1
      IA(NELEM)=I
      A(NELEM)=1.
      LA(NCOL)=NELEM
 9100 CONTINUE
      LA(NCOL+1)=NELEM+1
C
C
C         FILL IN COEFFICIENT MATRIX
C
      NCCGUB=1
      DO 9400 JJ=1,NUMVAR
      J1=KLO(JJ)
      J2=KRO(JJ)
      IF (J1.LT.J2)  GO TO 9300
C
      LJ=JJ
      IF(JJ.GE.19.A.JJ.LE.(18+ISTEP))LJ=19
      IF(JJ.GE.(19+ISTEP).A.JJ.LE.(18+2*ISTEP))LJ=20
      IF(JJ.GE.(19+2*ISTEP).A.JJ.LE.(18+3*ISTEP))LJ=21
      IF(JJ.GE.(19+3*ISTEP).A.JJ.LE.(18+4*ISTEP))LJ=22
      IF(JJ.GE.(19+4*ISTEP).A.JJ.LE.(18+5*ISTEP))LJ=23
      IF(JJ.GE.(19+5*ISTEP).A.JJ.LE.(18+6*ISTEP))LJ=24
      IF(JJ.GE.(19+6*ISTEP).A.JJ.LE.(18+7*ISTEP))LJ=25
      IF(JJ.GE.(19+7*ISTEP).A.JJ.LE.(18+8*ISTEP))LJ=26
      IF(JJ.GE.(19+8*ISTEP).A.JJ.LE.(18+9*ISTEP))LJ=27
      IF(JJ.GE.(19+9*ISTEP).A.JJ.LE.(18+10*ISTEP))LJ=28
      IF(JJ.GE.(19+10*ISTEP).A.JJ.LE.(17+11*ISTEP))LJ=29
      IF(JJ.GE.(18+11*ISTEP).A.JJ.LE.(16+12*ISTEP))LJ=30
      IF(JJ.GE.(17+12*ISTEP).A.JJ.LE.(15+13*ISTEP))LJ=31
      IF(JJ.GE.(16+13*ISTEP).A.JJ.LE.(14+14*ISTEP))LJ=32
      IF(JJ.GE.(15+14*ISTEP).A.JJ.LE.(13+15*ISTEP))LJ=33
      IF(JJ.GE.(14+15*ISTEP).A.JJ.LE.(12+16*ISTEP))LJ=34
      IF(JJ.GE.(13+16*ISTEP).A.JJ.LE.(11+17*ISTEP))LJ=35
      IF(JJ.GE.(12+17*ISTEP).A.JJ.LE.(10+18*ISTEP))LJ=36
      IF(JJ.GE.(11+18*ISTEP).A.JJ.LE.(9+19*ISTEP))LJ=37
      IF(JJ.GE.(10+19*ISTEP).A.JJ.LE.(8+20*ISTEP))LJ=38
      IF(JJ.GE.(9+20*ISTEP).A.JJ.LE.(7+21*ISTEP))LJ=39
      IF(JJ.GE.(8+21*ISTEP).A.JJ.LE.(6+22*ISTEP))LJ=40
      IF(JJ.GE.(7+22*ISTEP).A.JJ.LE.(5+23*ISTEP))LJ=41
      IF(JJ.EQ.(6+23* ISTEP))LJ=42
      IF(JJ.EQ.(7+23*ISTEP))LJ=43
      ITVAR=0
      IF(LJ.EQ.19)ITVAR=JJ-19+1
      IF(LJ.EQ.20)ITVAR=JJ-19-ISTEP+1
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      IF(LJ.EQ.21)ITVAR=JJ-19-2*ISTEP+1
      IF(LJ.EQ.22)ITVAR=JJ-19-3*ISTEP+1
      IF(LJ.EQ.23)ITVAR=JJ-19-4*ISTEP+1
      IF(LJ.EQ.24)ITVAR=JJ-19-5*ISTEP+1
      IF(LJ.EQ.25)ITVAR=JJ-19-6*ISTEP+1
      IF(LJ.EQ.26)ITVAR=JJ-19-7*ISTEP+1
      IF(LJ.EQ.27)ITVAR=JJ-19-8*ISTEP+1
      IF(LJ.EQ.28)ITVAR=JJ-19-9*ISTEP+1
      IF(LJ.EQ.29)ITVAR=JJ-19-10*ISTEP+1
      IF(LJ.EQ.30)ITVAR=JJ-18-11*ISTEP+1
      IF(LJ.EQ.31)ITVAR=JJ-17-12*ISTEP+1
      IF(LJ.EQ.32)ITVAR=JJ-16-13*ISTEP+1
      IF(LJ.EQ.33)ITVAR=JJ-15-14*ISTEP+1
      IF(LJ.EQ.34)ITVAR=JJ-14-15*ISTEP+1
      IF(LJ.EQ.35)ITVAR=JJ-13-16*ISTEP+1
      IF(LJ.EQ.36)ITVAR=JJ-12-17*ISTEP+1
      IF(LJ.EQ.37)ITVAR=JJ-11-18*ISTEP+1
      IF(LJ.EQ.38)ITVAR=JJ-10-19*ISTEP+1
      IF(LJ.EQ.39)ITVAR=JJ-9-20*ISTEP+1
      IF(LJ.EQ.40)ITVAR=JJ-8-21*ISTEP+1
      IF(LJ.EQ.41)ITVAR=JJ-7-22*ISTEP+1
      DO 10190 I=1,NMROWS
10190 YTEMP(I)=0.
      DISC=(1.+R)**(NLAG+NPURCH+NSS+ITVAR)
      DISC=1./DISC
      IF(ITVAR.GE.MA.AND.ITVAR.LT.MB)DISC=DISC*AMULT
      IF(ITVAR.GE.MB)DISC=DISC*BMULT
      GO TO (80100,80200,80300,80400,80500,80600,80700,80800,80900,
     181000,81100,81200,81300,81400,81500,81600,81700,81800,81900,82000,
     282100,82200,82300,82400,82500,82600,82700,82800,82900,83000,83100,
     383200,83300,83400,83500,83600,83700,83800,83900,84000,84100,84200,
     484300),IJ
80100 CONTINUE
C     HERE IF CB1
      YTEMP(1)=Z13
      YTEMP(4)=-Z5
      I=10+11*ISTEP
      YTEMP(I)=Z26
      I=12+11*ISTEP
      YTEMP(I)=-1.
      GO TO 85000
80200 CONTINUE
C     HERE IF BC2
      YTEMP(1)=Z15
      YTEMP(5)=-Z7
      I=10+11*ISTEP
      YTEMP(I)=Z27
      I=13+11*ISTEP
      YTEMP(I)=-1.
      GO TO 85000
80300 CONTINUE
C     HERE IF BW1
      YTEMP(1)=Z17
      YTEMP(2)=-Z1
      YTEMP(4)=-Z1
      YTEMP(6)=Z0
      YTEMP(7)=-1./KW1
      YTEMP(8)=-Z1/KW1
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      I=10+11*ISTEP
      YTEMP(I)=Z28
      I=14+11*ISTEP
      YTEMP(I)=-1.
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      IF(KC2.NE.0)I=I+4
      IF(KC3.NE.0)I=I+1
      IF(NSS.GT.0)I=I+1
      IF(KC4.NE.2)GO TO 85000
      I=I+1
      YTEMP(I)=1.
      GO TO 85000
80400 CONTINUE
C     HERE IF PW2
      YTEMP(1)=Z19
      YTEMP(3)=-Z3
      YTEMP(5)=-Z3
      YTEMP(6)=Z9
      YTEMP(7)=-1./KW2
      YTEMP(8)=-Z3/KW2
      I=10+11*ISTEP
      YTEMP(I)=Z29
      I=15+11*ISTEP
      YTEMP(I)=-1.
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      IF(KC2.NE.0)I=I+4
      IF(KC3.NE.0)I=I+1
      IF(NSS.GT.0)I=I+1
      IF(KC4.NE.2)GO TO 85000
      I=I+1
      YTEMP(I)=1.
      GO TO 85000
80500 CONTINUE
C     HERE IF SLPPC1
      YTEMP(1)=Z14
      YTEMP(4)=-Z6
      I=10+11*ISTEP
      YTEMP(I)=Z30
      I=12+11*ISTEP
      YTEMP(I)=1.-FLOAT(NPURCH)
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      I=I+1
      IF(KC2.NE.0)YTEMP(I)=1.
      GO TO 85000
80600 CONTINUE
C     HERE IF SLPNC1
      YTEMP(1)=-Z14
      YTEMP(4)=Z6
      I=10+11*ISTEP
      YTEMP(I)=-Z30
      I=12+11*ISTEP
      YTEMP(I)=FLOAT(NPURCH)-1.
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      I=I+1
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      IF(KC2.NE.0)YTEMP(I)=-1.
      GO TO 85000
80700 CONTINUE
C     HERE IF SLPPC2
      YTEMP(1)=Z16
      YTEMP(5)=-Z8
      I=10+11*ISTEP
      YTEMP(I)=Z31
      I=13+11*ISTEP
      YTEMP(I)=1.-FLOAT(NPURCH)
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      I=I+2
      IF(KC2.NE.0)YTEMP(I)=1.
      GO TO 85000
80800 CONTINUE
C     HERE IF SLPNC2
      YTEMP(1)=-Z16
      YTEMP(5)=Z8
      I=10+11*ISTEP
      YTEMP(I)=-Z31
      I=13+11*ISTEP
      YTEMP(I)=FLOAT(NPURCH)-1.
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      I=I+2
      IF(KC2.NE.0)YTEMP(I)=-1.
      GO TO 85000
80900 CONTINUE
C     HERE IF SLPPW1
      YTEMP(1)=Z18
      YTEMP(2)=-Z2
      YTEMP(4)=-Z2
      YTEMP(6)=Z10
      YTEMP(8)=-Z2/KW1
      I=10+11*ISTEP
      YTEMP(I)=Z32
      I=14+11*ISTEP
      YTEMP(I)=1.-FLOAT(NPURCH)
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      I=I+3
      IF(KC2.NE.0)YTEMP(I)=1.
      GO TO 85000
81000 CONTINUE
C     HERE IF SLPNW1
      YTEMP(1)=-Z18
      YTEMP(2)=Z2
      YTEMP(4)=Z2
      YTEMP(6)=-Z10
      YTEMP(8)=Z2/KW1
      I=10+11*ISTEP
      YTEMP(I)=-Z32
      I=14+11*ISTEP
      YTEMP(I)=FLOAT(NPURCH)-1.
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      I=I+3
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      IF(KC2.NE.0)YTEMP(I)=-1.
      GO TO 85000
81100 CONTINUE
C     HERE IF SLPPW2
      YTEMP(1)=Z20
      YTEMP(3)=-Z4
      YTEMP(5)=-Z4
      YTEMP(6)=Z11
      YTEMP(8)=-Z4/KW2
      I=10+11*ISTEP
      YTEMP(I)=Z33
      I=15+11*ISTEP
      YTEMP(I)=1.-FLOAT(NPURCH)
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      I=I+4
      IF(KC2.NE.0)YTEMP(I)=1.
      GO TO 85000
81200 CONTINUE
C     HERE IF SLPNW2
      YTEMP(1)=-Z20
      YTEMP(3)=Z4
      YTEMP(5)=Z4
      YTEMP(6)=-Z11
      YTEMP(8)=Z4/KW2
      I=10+11*ISTEP
      YTEMP(I)=-Z33
      I=15+11*ISTEP
      YTEMP(I)=FLOAT(NPURCH)-1.
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      I=I+4
      IF(KC2.NE.0)YTEMP(I)=-1.
      GO TO 85000
81300 CONTINUE
C     HERE IF EC1
      YTEMP(1)=Z21
      YTEMP(4)=1.
      LL=11
      LU=10+ISTEP
      DO 81305 I=LL,LU
      ITCONS=I-LL+1
      IF(ITCONS.EQ.1.AND.(ITCONS-LP1).GE.(1-NSS))YTEMP(I)=1.
      IF(ITCONS.EQ.1.AND.(ITCONS-LP1).LT.(1-NSS))YTEMP(I)=1.-DC1
      IF(ITCONS.GE.2.AND.(ITCONS-LP1).LE.0.AND.(ITCONS-LP1).GE.(1-NSS))
     1YTEMP(I)=DC1
81305 CONTINUE
      I=11+11*ISTEP
      YTEMP(I)=Z34
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      IF(KC2.NE.0)I=I+4
      I=I+1
      IF(KC3.NE.0)YTEMP(I)=1.
      GO TO 85000
81400 CONTINUE
C     HERE IF EC2
      YTEMP(1)=Z22
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      YTEMP(5)=1.
      LL=I1+ISTEP
      LU=I0+2*ISTEP
      DO 81405 I=LL,LU
      ITCONS=I-LL+1
      IF(ITCONS.EQ.1.AND.(ITCONS-LP2).GE.(1-NSS))YTEMP(I)=1.
      IF(ITCONS.EQ.1.AND.(ITCONS-LP2).LT.(1-NSS))YTEMP(I)=1.-DC2
      IF(ITCONS.GE.2.AND.(ITCONS-LP2).LE.0.AND.(ITCONS-LP2).GE.(1-NSS))
     1YTEMP(I)=DC2
81405 CONTINUE
      I=I1+11*ISTEP
      YTEMP(I)=Z35
      I=I5+11*ISTEP
      IF(KC1.NE.0)I=I+3
      IF(KC2.NE.0)I=I+4
      I=I+1
      IF(KC3.NE.0)YTEMP(I)=1.
      GO TO 85000
81500 CONTINUE
C     HERE IS FW1
      YTEMP(1)=Z23
      YTEMP(2)=1.
      YTEMP(4)=1.
      LL=I1
      LU=I0+ISTEP
      DO 81505 I=LL,LU
      ITCONS=I-LL+1
      IF((ITCONS-LP1).LE.0.AND.(ITCONS-LP1).GE.(1-NSS))YTEMP(I)=DW1
81505 CONTINUE
          LL=I1+2*ISTEP
      LU=I0+3*ISTEP
      DO 81510 I=LL,LU
      ITCONS=I-LL+1
      IF(ITCONS.EQ.1)YTEMP(I)=1.
      IF(ITCONS.GE.2.AND.(ITCONS-LCW1).LE.0.AND.(ITCONS-LCW1).GE.(1-NSS)
     1)YTEMP(I)=DW1
81510 CONTINUE
      I=I1+11*ISTEP
      YTEMP(I)=Z36
      I=I5+11*ISTEP
      IF(KC1.NE.0)I=I+3
      IF(KC2.NE.0)I=I+4
      IF(KC3.NE.0)I=I+1
      IF(KC3.NE.0)YTEMP(I)=1.
      I=I+1
      IF(NSS.GT.0)YTEMP(I)=1./KW1
      GO TO 85000
81600 CONTINUE
C     HERE IS FW2
      YTEMP(1)=Z24
      YTEMP(3)=1.
      YTEMP(5)=1.
      LL=I1+ISTEP
      LU=I0+2*ISTEP
      DO 81605 I=LL,LU
      ITCONS=I-LL+1
      IF((ITCONS-LP2).LE.0.AND.(ITCONS-LP2).GE.(1-NSS))YTEMP(I)=DW2
81605 CONTINUE
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      LL=11+3*ISTEP
      LU=10+4*ISTEP
      DO 81610 I=LL,LU
      ITCONS=I-LL+1
      IF(ITCONS.EQ.1)YTEMP(I)=1.
      IF(ITCONS.GE.2.AND.(ITCONS-LCW2).LE.0.AND.(ITCONS-LCW2).GE.(1-NSS)
     1)YTEMP(I)=DW2
81610 CONTINUE
      I=11+11*ISTEP
      YTEMP(I)=Z37
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      IF(KC2.NE.0)I=I+4
      IF(KC3.NE.0)I=I+1
      IF(KC3.NE.0)YTEMP(I)=1.
      I=I+1
      IF(NSS.GT.0)YTEMP(I)=1./KW2
      GO TO 86000
81700 CONTINUE
C     HERE IF ES
      YTEMP(I)=Z25
      YTEMP(6)=-1.
      YTEMP(9)=-1.
      I=11+6*ISTEP
      YTEMP(I)=1.
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      IF(KC2.NE.0)I=I+4
      IF(KC3.NE.0)I=I+1
      IF(KC3.NE.0)YTEMP(I)=-RATIO
      I=I+1
      IF(NSS.GE.1)YTEMP(I)=-DS
      GO TO 86000
81800 CONTINUE
C     HERE IF EPREP
      YTEMP(I)=VPREP/((1.+R)**(NSS+NPURCH))
      YTEMP(9)=1.
      YTEMP(10)=1.
      I=11+6*ISTEP
      YTEMP(I)=-1.
      I=11+7*ISTEP
      YTEMP(I)=1.
      GO TO 86000
81900 CONTINUE
C     HERE IF C1
      YTEMP(I)=VC1*DISC
      IF (ITVAR.EQ.ISTEP) YTEMP(I)=VBSALV*DISC
      I=10
      I=I+ITVAR
      YTEMP(I)=-1.
      I=I+1
      IF(I.LE.(10+ISTEP))YTEMP(I)=1.-DC1
      GO TO 86000
86000 CONTINUE
C     HERE IF C2
      YTEMP(I)=VC2*DISC
      IF (ITVAR.EQ.ISTEP) YTEMP(I)=VBSALV*DISC
      I=10+ISTEP
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      I=I+ITVAR
      YTEMP(I)=-1.
      I=I+1
      IF(I.LE.(10+2*ISTEP))YTEMP(I)=1.-DC2
      GO TO 85000
85100 CONTINUE
C     HERE IF W1
      YTEMP(1)=DISC*(VW1+VPW1/KW1)
      IF (ITVAR.EQ.ISTEP) YTEMP(1)=VBSALV*DISC
      I=10+2*ISTEP
      I=I+ITVAR
      YTEMP(I)=-1.
      I=I+1
      IF(I.LE.(10+3*ISTEP))YTEMP(I)=1.-DW1
      I=10+6*ISTEP
      I=I+ITVAR
      YTEMP(I)=1./KW1
      I=9+10*ISTEP
      I=I+ITVAR
      YTEMP(I)=VPW1/KW1
      I=15+11*ISTEP
      I=I+3
      IF (KC1.NE.0.AND.ITVAR.EQ.ISTEP) YTEMP(I)=-1./KW1
      GO TO 85000
82200 CONTINUE
C     HERE IF W2
      YTEMP(1)=DISC*(VW2+VPW2/KW2)
      IF (ITVAR.EQ.ISTEP) YTEMP(1)=VBSALV*DISC
      I=10+3*ISTEP
      I=I+ITVAR
      YTEMP(I)=-1.
      I=I+1
      IF(I.LE.(10+4*ISTEP))YTEMP(I)=1.-DW2
      I=10+6*ISTEP
      I=I+ITVAR
      YTEMP(I)=1./KW2
      I=9+10*ISTEP
      I=I+ITVAR
      YTEMP(I)=VPW2/KW2
      I=15+11*ISTEP
      I=I+ 3
      IF (KC1.NE.0.AND.ITVAR.EQ.ISTEP) YTEMP(I)=-1./KW2
      GO TO 85000
82300 CONTINUE
C     HERE IF H1
      YTEMP(1)=DISC*(VH1+VPH1/KH1)
      IF (ITVAR.EQ.ISTEP) YTEMP(1)=VBSALV*DISC
      I=10+4*ISTEP
      I=I+ITVAR
      YTEMP(I)=-1.
      I=I+1
      IF(I.LE.(10+5*ISTEP))YTEMP(I)=1.-DH1
      I=10+6*ISTEP
      I=I+ITVAR
      YTEMP(I)=1./KH1
      I=9+10*ISTEP
      I=I+ITVAR
      YTEMP(I)=VPH1/KH1
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      I=15+11*ISTEP
      I=I+3
      IF (KC1.NE.0.AND.ITVAR.EQ.ISTEP) YTEMP(I)=-1./KH1
      GO TO 85000
82400 CONTINUE
C     HERE IF H2
      YTEMP(1)=DISC*(VH2+VPH2/KH2)
      IF (ITVAR.EQ.ISTEP) YTEMP(1)=VHSALV*DISC
      I=10+5*ISTEP
      I=I+ITVAR
      YTEMP(I)=-1.
      I=I+1
      IF(I.LE.10+6*ISTEP)YTEMP(I)=1.-DH2
      I=10+6*ISTEP
      I=I+ITVAR
      YTEMP(I)=1./KH2
      I=9+10*ISTEP
      I=I+ITVAR
      YTEMP(I)=VPH2/KH2
      I=15+11*ISTEP
      I=I+3
      IF (KC1.NE.0.AND.ITVAR.EQ.ISTEP) YTEMP(I)=-1./KH2
      GO TO 85000
82500 CONTINUE
C     HERE IF FC1
      YTEMP(1)=VPC1*DISC
      I=10
      I=I+ITVAR+LP1
      IF(I.LE.(10+ISTEP))YTEMP(I)=1.
      I=9+10*ISTEP
      I=I+ITVAR
      YTEMP(I)=VPC1
      GO TO 85000
82600 CONTINUE
C     HERE IF FC2
      YTEMP(1)=VPC2*DISC
      I=10+ISTEP
      I=I+ITVAR+LP2
      IF(I.LE.(10+2*ISTEP))YTEMP(I)=1.
      I=9+10*ISTEP
      I=I+ITVAR
      YTEMP(I)=VPC2
      GO TO 85000
82700 CONTINUE
C     HERE IF S
      YTEMP(1)=VS*DISC
      IF(ITVAR.EQ.ISTEP)YTEMP(1)=VSSALV*DISC
      I=10+6*ISTEP
      I=I+ITVAR
      YTEMP(I)=-1.
      I=I+1
      IF(I.LE.(10+7*ISTEP))YTEMP(I)=1.-DS
      I=15+11*ISTEP
      I=I+1
      IF (KC1.NE.0.AND.ITVAR.EQ.ISTEP) YTEMP(I)=-1.
      GO TO 85000
82800 CONTINUE
C     HERE IF SP
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      YTEMP(1)=VSP*DISC
      IF(ITVAR.EQ.ISTEP)YTEMP(I)=VSPALV*DISC
      I=10+7*ISTEP
      I=I+ITVAR
      YTEMP(I)=-1
      I=I+1
      IF(I.LE.(10+8*ISTEP))YTEMP(I)=1.-DSP
      I=10+8*ISTEP
      I=I+ITVAR
      YTEMP(I)=1.
      I=15+11*ISTEP
      I=I+2
      IF (KC1.NE.0.AND.ITVAR.EQ.ISTEP) YTEMP(I)=-1.
      GO TO 85000
82900 CONTINUE
C     HERE IF PIPE
      YTEMP(1)=VPIPE*DISC
      I=10+6*ISTEP
      I=I+ITVAR
      IF(I.LE.(10+7*ISTEP))YTEMP(I)=-1.
      I=10+7*ISTEP
      I=I+ITVAR+LPIPE
      IF(I.LE.(10+8*ISTEP))YTEMP(I)=1.
      I=10+9*ISTEP
      I=I+ITVAR
      YTEMP(I)=1.
      GO TO 85000
83000 CONTINUE
C     HERE IF TCW1
      YTEMP(1)=VCW1*DISC
      I=10
      I=I+ITVAR
      IF(I.LE.(10+ISTEP))YTEMP(I)=-1.
      I=10+2*ISTEP
      I=I+ITVAR+LCW1
      IF(I.LE.(10+3*ISTEP))YTEMP(I)=1.
      GO TO 85000
83100 CONTINUE
C     HERE IF TCW2
      YTEMP(1)=VCW2*DISC
      I=10+ISTEP
      I=I+ITVAR
      IF(I.LE.(10+2*ISTEP))YTEMP(I)=-1.
      I=10+3*ISTEP
      I=I+ITVAR+LCW2
      IF(I.LE.(10+4*ISTEP))YTEMP(I)=1.
      GO TO 85000
83200 CONTINUE
C     HERE IF TCH1
      YTEMP(1)=VCH1*DISC
      I=10
      I=I+ITVAR
      IF(I.LE.(10+ISTEP))YTEMP(I)=-1.
      I=10+4*ISTEP
      I=I+ITVAR+LCH1
      IF(I.LE.(10+5*ISTEP))YTEMP(I)=1.
      GO TO 85000
83300 CONTINUE
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C       HERE IF TCH2
        YTEMP(1)=VCH2*DISC
        I=10+ISTEP
        I=I+ITVAR
        IF(I.LE.(10+2*ISTEP))YTEMP(I)=-1.
        I=10+5*ISTEP
        I=I+ITVAR+LCH2
        IF(I.LE.(10+6*ISTEP))YTEMP(I)=1.
        GO TO 85000
83400 CONTINUE
C       HERE IF TWH1
        SUM=0.
        KK=1
        KKK=LWH1
        DO 83405I=KK,KKK
83405 SUM=SUM+(VPW1/KW1)*DISC*(1./((1.+R)**(I-1)))
        YTEMP(1)=SUM+VWH1*DISC
        I=10+2*ISTEP
        I=I+ITVAR
        IF(I.LE.(10+3*ISTEP))YTEMP(I)=-1.
        I=10+4*ISTEP
        I=I+ITVAR+LWH1
        IF(I.LE.(10+5*ISTEP))YTEMP(I)=1.
        KK=11+6*ISTEP
        KKK=10+7*ISTEP
        DO 83410I=KK,KKK
        II=I-(10+6*ISTEP)
        IF(II.LT.ITVAR)GOTO83410
        IF(II.GE.ITVAR+LWH1)GOTO83410
        YTEMP(I)=1./KW1
83410 CONTINUE
        KK=10+10*ISTEP
        KKK=9+11*ISTEP
        DO83415I=KK,KKK
        II=I-(9+10*ISTEP)
        IF(II.LT.ITVAR)GOTO83415
        IF(II.GE.ITVAR+LWH1)GOTO83415
        YTEMP(I)=VPW1/KW1
83415 CONTINUE
        GO TO 85000
83500 CONTINUE
C       HERE IF TWH2
        SUM=0.
        KK=1
        KKK=LWH2
        DO 83505I=KK,KKK
83505 SUM=SUM+(VPW2/KW2)*DISC*(1./((1.+R)**(I-1)))
        YTEMP(1)=SUM+VWH2*DISC
        I=10+3*ISTEP
        I=I+ITVAR
        IF(I.LE.(10+4*ISTEP))YTEMP(I)=-1.
        I=10+5*ISTEP
        I=I+ITVAR+LWH2
        IF(I.LE.(10+6*ISTEP))YTEMP(I)=1.
        KK=11+6*ISTEP
        KKK=10+7*ISTEP
        DO 83510I=KK,KKK
        II=I-(10+6*ISTEP)
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      IF(II.LT.ITVAR)GOTO83510
      IF(II.GE.ITVAR+LWH2)GOTO83510
      YTEMP(I)=1./KW2
83510 CONTINUE
      KK=10+10*ISTEP
      KKK=9+11*ISTEP
      DO83515I=KK,KKK
      II=I-(9+10*ISTEP)
      IF(II.LT.ITVAR)GOTO83515
      IF(II.GE.ITVAR+LWH2)GOTO83515
      YTEMP(I)=VPW2/KW2
83515 CONTINUE
      GO TO 85000
83600 CONTINUE
C     HERE IF TWC1
      YTEMP(1)=VWC1*DISC
      I=10
      I=I+ITVAR+LWC1
      IF(I.LE.(10+ISTEP))YTEMP(I)=1.
      I=10+2*ISTEP
      I=I+ITVAR
      IF(I.LE.(10+3*ISTEP))YTEMP(I)=-1.
      GO TO 85000
83700 CONTINUE
C     HERE IF TWC2
      YTEMP(1)=VWC2*DISC
      I=10+ISTEP
      I=I+ITVAR+LWC2
      IF(I.LE.(10+2*ISTEP))YTEMP(I)=1.
      I=10+3*ISTEP
      I=I+ITVAR
      IF(I.LE.(10+4*ISTEP))YTEMP(I)=-1.
      GO TO 85000
83800 CONTINUE
C     HERE IF THC1
      YTEMP(1)=VHC1*DISC
      I=10
      I=I+ITVAR+LHC1
      IF(I.LE.(10+ISTEP))YTEMP(I)=1.
      I=10+4*ISTEP
      I=I+ITVAR
      IF(I.LE.(10+5*ISTEP))YTEMP(I)=-1.
      GO TO 85000
83900 CONTINUE
C     HERE IF THC2
      YTEMP(1)=VHC2*DISC
      I=10+ISTEP
      I=I+ITVAR+LHC2
      IF(I.LE.(10+2*ISTEP))YTEMP(I)=1.
      I=10+5*ISTEP
      I=I+ITVAR
      IF(I.LE.(10+6*ISTEP))YTEMP(I)=-1.
      GO TO 85000
84000 CONTINUE
C     HERE IF THW1
      YTEMP(1)=VHW1*DISC
      I=10+2*ISTEP
      I=I+ITVAR+LHW1
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      IF(I.LE.(10+3*ISTEP))YTEMP(I)=1.
      I=10+4*ISTEP
      I=I+ITVAR
      IF(I.LE.(10+5*ISTEP))YTEMP(I)=-1.
      GO TO 85000
84100 CONTINUE
C     HERE IF THW2
      YTEMP(1)=VHW2*DISC
      I=10+3*ISTEP
      I=I+ITVAR+LHW2
      IF(I.LE.(10+4*ISTEP))YTEMP(I)=1.
      I=10+5*ISTEP
      I=I+ITVAR
      IF(I.LE.(10+6*ISTEP))YTEMP(I)=-1.
      GO TO 85000
84200 CONTINUE
C     HERE IF IBW1
      YTEMP(1)=(VW1+VPW1/KW1)*ZZ1+ZZ2*VS/KW1+ZZ3*VCW1+VPC1*ZZ4
      YTEMP(2)=-((1.-DW1)**(NPURCH-1))
      YTEMP(4)=YTEMP(2)
      YTEMP(6)=ZZ5/KW1
      YTEMP(7)=-1./KW1
      YTEMP(8)= YTEMP(2)/KW1
      I=10+11*ISTEP
      ZZZ=0.
      DO 84205  II=1,NPURCH
84205 ZZZ=ZZZ+((1.-DW1)**(II-1))
      YTEMP(I)=VPC1+ZZZ*VPW1/KW1
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      IF(KC2.NE.0)I=I+4
      IF(KC3.NE.0)I=I+1
      IF(NSS.GT.0)I=I+1
      IF(KC4.NE.1)GO TO 85000
      I=I+1
      YTEMP(I)=1.
      GO TO 85000
84300 CONTINUE
C     HERE IF IBW2
      YTEMP(1)=(VW2+VPW2/KW2)*ZY1+ZY2*VS/KW2+ZY3*VCW2+VPC2*ZY4
      YTEMP(3)=-((1.-DW2)**(NPURCH-1))
      YTEMP(5)=YTEMP(3)
      YTEMP(6)=ZY5/KW2
      YTEMP(7)=-1./KW2
      YTEMP(8)= YTEMP(3)/KW2
      I=10+11*ISTEP
      ZZY=0.
      DO 84305 II=1,NPURCH
84305 ZZY=ZZY+((1.-DW2)**(II-1))
      YTEMP(I)=VPC2+ZZY*VPW2/KW2
      I=15+11*ISTEP
      IF(KC1.NE.0)I=I+3
      IF(KC2.NE.0)I=I+4
      IF(KC3.NE.0)I=I+1
      IF(NSS.GT.0)I=I+1
      IF(KC4.NE.1)GO TO 85000
      I=I+1
      YTEMP(I)=1.
```

```
      GO TO 85000
C
85000 CONTINUE
C
      DO 9270 I=1,NMROWS
      YTEMP1=YTEMP(I)
      IF (ABS(YTEMP1).LE.ZTOLZE)  GO TO 9270
      NELEM=NELEM+1
      IA(NELEM)=I
      A(NELEM)=YTEMP1
 9270 CONTINUE
      NCOL=NCOL+1
      LA(NCOL+1)=NELEM+1
      GO TO 9400
C
 9300 DO 9390 J=J1,J2
C
      DO 9380 I=1,NMROWS
      CALL GETPHI(I,JJ,CUTS(J),ATEMP)
      IF (ABS(ATEMP).LE.ZTOLZE)  GO TO 9380
      NELEM=NELEM+1
      IA(NELEM)=I
      A(NELEM)=ATEMP
 9380 CONTINUE
      NELEM=NELEM+1
      IA(NELEM)=NMROWS+NCOGUB
      A(NELEM)=1.
      NCOL=NCOL+1
      LA(NCOL+1)=NELEM+1
 9390 CONTINUE
      NCOGUB=NCOGUB+1
 9400 CONTINUE
      IF(NELEM.GT.MAXA)CALL ERR(3)
 200  FORMAT(16A5)
 250  FORMAT(8A10)
C     *****DONE READING IN DATA
C     ******SET UP STARTING BASIS
            DO 9200 I=1,NROW
            JH(I)=I
 9200       KINBAS(I)=I
      IF(K5.EQ.1)CALL SCAIL
      IF(K2.NE.0)360,370
 360  PRINT 361
 361  FORMAT(1H0,55HPACKED MATRIX BY COLUMNS, ROW NUMBER BELOW EACH ELEM
     1ENT)
      IXI=NELEM/11+1
      DO 365 I=1,IXI
      KK=(I-1)*11+1
      IF(KK.GT.NELEM)GO TO 370
      K=KK+10
      IF(K.GT.NELEM)K=NELEM
      PRINT 366,(A(J),J=KK,K)
      PRINT 367,(IA(J),J=KK,K)
 366  FORMAT(1H0,11G12.4)
 367   FORMAT(1H ,11I12)
 365  CONTINUE
 370  CONTINUE
      PRINT 200
```

```
 290   FORMAT(1H1,19HSTARTING TO ITERATE)
       PRINT 300
 300   FORMAT(1H0,4X,13HSTAGE PROBLEM,7X,11HLOWER BOUND,9X,11HUPPER BOUND
      1,6X,18HBRANCHING VARIABLE,//)
C      *****READY TO START LOOP
C      *****READY TO START LOOP
C      *****READY TO START LOOP
C      *****READY TO START LOOP
             DO 980 I=1,LSTMAX
             IBRVR(I)=0
 980         ZLSLB(I)=1.E80
       PARENT=0.0
       LSTKR(1)=0
       LSTKL(1)=0
       STGPRB=0.0
       LSTNUM=0
       NLP=0
       IBRPAR=0
       NOLFT=1
             DO 990I=1,NUMVAR
             KL(I)=KLO(I)
 990         KR(I)=KRO(I)
 1000  PRINT 1005,STGPRB
 1005  FORMAT(1H0,8X,F6.1)
       NOLFT=NOLFT-1
       NLP=NLP+1
       IF(NLP.GT.MAXLP)CALL ERR(4)
C
       JK=KPO(NUMVAR)
       DO 6300 J=1,JK
C
 6300  W(J)=0.0
       CALL LINERG
       IF(KI.EQ.1)CALL LPPP(W)
       IF(LFLG.NE.1)GO TO 1010
       IF(NLP.EQ.1)CALL ERR(5)
       PRINT 1008
 1008  FORMAT(1H+,24X,11HLP. INFEAS.)
       GO TO 5000
 1010  IF(VAL-BUBTOL.LE.BUB)GO TO 1020
       PRINT 1015
 1015  FORMAT(1H+,25X,9HLB GT BUB)
       GO TO 5000
C      *****PUT THIS PROBLEM ON THE LIST, FIND THE NEXT EMPTY SPOT
 1020  IF (LSTNUM.GT.LSTMAX)CALL ERR(6)
       PRINT 1025,VAL
 1025  FORMAT(1H+,25X,G12.4)
       LSTNUM=LSTNUM+1
       ZLSTNO(LSTNUM)=STGPRB
       ZLSTPA(LSTNUM)=PARENT
       IF(IBRPAR.NE.0)LSTKL(LSTNUM)=KL(IBRPAR)
       IF(IBRPAR.NE.0)LSTKR(LSTNUM)=KR(IBRPAR)
       ZLSLB(LSTNUM)=VAL
C      *****NOT DONE WITH LIST YET
C      *****CREATE XCODED, COMPACTIFIED VERSION OF X--ELEMENTS OF XCODED
C      *****ARE X, IF X CORRESPONDS TO A LINEAR VARIABLE, OR ELSE THE
C      *****MEAN OF GUBBED VARIABLES
             DO 1030 I=1,NUMVAR
```

```
          IF(KLO(I).NE.KRO(I))GO TO 1040
          II=KLO(I)
          XCODED(I)=W(II)
          GO TO 1030
 1040     XCODED(I)=0.0
                IW=KLO(I)
                IZ=KRO(I)
                DO 1050 II=IW,IZ
 1050           XCODED(I)=XCODED(I)+W(II)*CUTS(II)
 1030     CONTINUE
C     *****XCODED CREATED. CHECK IT
          DO 1060 I=1,NUMVAR
          IF(KLO(I).EQ.KRO(I))GO TO 1060
          IL=KLO(I)
           IR=KRO(I)
          XXL=CUTS(IL)-CUTTOL
          XXR=CUTS(IR)+CUTTOL
      IF(XCODED(I).LT.XXL)CALL ERR(7)
      IF(XCODED(I).GT.XXR)CALL ERR(7)
 1060 CONTINUE
C     *****NOW WE WILL TRY TO FIND AN UPPER BOUND AND ALSO A
C     *****BRANCHING VARIABLE
      IFEAS=0
      DIFFMA=0.0
      IBRVR(LSTNUM)=0
      UB=1.E70
          DO 2000 IROW=1,NMROWS
          IF(ICHK(IROW).EQ.1)GO TO 2000
          ROWVAL=0.0
                DO 2010 I=1,NUMVAR
C     *****SET INDEX AND FRAC
      IW=KLO(I)
      IZ=KRO(I)
      IF(IW.EQ.IZ)7005,7010
 7005 INDEX=-1
      FRAC=0.0
      GO TO 7900
 7010 IH=IZ-1
      DO 7015 IJ=IW,IH
      IK=IJ+1
      IF(CUTS(IJ).LE.XCODED(I).AND.CUTS(IK).GT.XCODED(I))GO TO 7025
 7015 CONTINUE
      XXX=CUTS(IW)-XCODED(I)
      XXX=ABS(XXX)
      IF(XXX.LT.CUTTOL)GO TO 7016
      XXX=XCODED(I)-CUTS(IZ)
      XXX=ABS(XXX)
      IF(XXX.LT.CUTTOL)GO TO 7017
      CALL ERR(7)
 7025 FRAC=(XCODED(I)-CUTS(IJ))/(CUTS(IK)-CUTS(IJ))
      INDEX=IJ
      GO TO 7900
 7016 INDEX=IW
      FRAC=0.0
      GO TO 7900
 7017 INDEX=IZ
      FRAC=0.0
 7900 CONTINUE
```

```
                 DIFF=0.0
                      DO 2020 IJ=IW,IZ
                      II=IJ+NROW
                      INDCOL=LA(II)
                      INDNXT=LA(II+1)-1
                           DO 2030 III=INDCOL,INDNXT
                           IF(IA(III).NE.IROW)GO TO 2030
                           IF(INDEX.NE.-1)DIFF=DIFF-W(IJ)*A(III)
                           IF(INDEX.EQ.IJ)DIFF=DIFF+(1.-FRAC)*A(III)
                           IF(INDEX.EQ.-1)ROWVAL=ROWVAL+XCODED(I)*A(III)
                           IF(INDEX.EQ.IJ)ROWVAL=ROWVAL+(1.-FRAC)*A(III)
                           IF((INDEX+1).EQ.IJ)DIFF=DIFF+FRAC*A(III)
                           IF((INDEX+1).EQ.IJ)ROWVAL=ROWVAL+FRAC*A(III)
 2030                      CONTINUE
 2020                 CONTINUE
      IF(ISTYPE(IROW).EQ.-1)DIFF=ABS(DIFF)
                 IF(DIFF.LT.DIFFMA+DIFFTO)GO TO 2010
                 DIFFMA=DIFF
      FLAG(LSTNUM)=INDEX
      FLAG(LSTNUM)=FLAG(LSTNUM)+FRAC
                 IBRVR(LSTNUM)=I
 2010            CONTINUE
            IF(ISTYPE(IROW))2040,2050,2060
 2050       UB=ROWVAL
            GO TO 2000
 2060 IF(B(IROW))2061,2062,2063
 2061 IF(ROWVAL.LE.(B(IROW)*(1.-FEASIL)))GO TO 2000
      IFEAS=1
      GO TO 2000
 2062 IF(ROWVAL.LE.FEASIL)GO TO 2000
      IFEAS=1
      GO TO 2000
 2063 IF(ROWVAL.LE.(B(IROW)*(1.+FEASIL)))GO TO 2000
      IFEAS=1
      GO TO 2000
 2040       IF(ABS(B(IROW)).EQ.0.0)GO TO 2070
            XXX=1.-ABS(ROWVAL/B(IROW))
            IF(ABS(XXX).LT.FEASIL)GO TO 2000
            IFEAS=1
            GO TO 2000
 2070       IF(ABS(ROWVAL).LE.FEASIL)GO TO  2000
            IFEAS=1
 2000       CONTINUE
C     *****DONE--WE HAVE PICKED A BRANCHING VARIABLE AND STORED IT ON
C     *****THE LIST WHILE TESTING  FOR FEASIBILITY
      IF(IFEAS.NE.1)GO TO 3000
      PRINT 2005,IBRVR(LSTNUM)
 2005 FORMAT(1H+,49X,4HNONE,16X,I6)
      GO TO 5000
 3000 PRINT 3005,UB,IBRVR(LSTNUM)
 3005 FORMAT(1H+,45X,G12.4,12X,I6)
      IF(IXPRIN.EQ.1)CALL  XPRINT(XCODED)
      IF(UB.LT.BUB)GO TO 3010
      GO TO 5000
 3010 BUB=UB
            DO 3020 I=1,NUMVAR
C     *****NOW BEGIN BRANCHING PROCEDURE
 3020       XBEST(I)=XCODED(I)
```

```
 5000 IF(NOLFT.EQ.0)GO TO 5050
C      *****SOLVE NEXT PROBLEM IN THIS STAGE
      KL(IBRPAR)=KBL(NOLFT)
      KR(IBRPAR)=KBR(NOLFT)
      STGPRB=STGPRB+.1
      GO TO 1500
C      *****WE ARRIVE HERE IF WE ARE DONE WITH A STAGE
 5050 NUM=0
      BLB=1.E70
            DO 5060 I=1,LSTNUM
            IF(ZLSLB(I).GE.BLB)GO TO 5060
            NUM=I
            BLB=ZLSLB(I)
 5060       CONTINUE
      IF(BLB.GE.1.E70)CALL ERR(8)
      IF(BLB.GE.BUB-DONTOL)GO TO 8000
C      *****NUM IS THE ENTRY ON THE LIST ON WHICH WE ARE TO BRANCH
 5063 FORMAT(1H0,20HDONE WITH THIS STAGE)
      IF(IBRVR(NUM).NE.0)GO TO 5064
      CALL ERR(9)
 5064 PRINT 5063
      PRINT 5065,BLB,BUB,ZLSTNO(NUM),IBRVR(NUM)
 5065 FORMAT(1H ,6HBLB=  ,G12.4,8H, BUB=  ,G12.4,22H, BRANCHING ON PROBL
     1EM,F5.1,17H, VARIABLE NUMBER,I6)
      IF(K4.EQ.1)PRINT 50651
50651 FORMAT(1H0,32H**********PRESENT STATUS OF LIST)
      IF(K4.EQ.1)PRINT 50652
50652 FORMAT(1H0,6HPROBNO,5X,6HPARENT,5X,6HLISTKL,5X,6HLISTKR,5X,
     111HLOWER BOUND,6X,12HBRANCH. VAR.,8X,4HFLAG,/)
      IF(K4.EQ.1)50653,50657
50653 DO 50009 I=1,LSTNUM
      PRINT 50001,ZLSTNO(I),ZLSTPA(I), LSTKL(I), LSTKR(I)
50001 FORMAT(1H ,F6.1,5X,F6.1,5X,I5,6X,I5)
      IF(ZLSLB(I).GE.1.E70)50002,50004
50002 PRINT 50003,IBRVR(I),FLAG(I)
50003 FORMAT(1H+,48X,3HOFF,4X,9X,I4,9X,F10.3)
      GO TO 50009
50004 PRINT 50005,ZLSLB(I),IBRVR(I),FLAG(I)
50005 FORMAT(1H+,44X,G11.3,9X,I4,9X,F10.3)
50009 CONTINUE
      PRINT 50656
50656 FORMAT(1H0)
50657 CONTINUE
      PARENT=ZLSTNO(NUM)
      IBRPAR=IBRVR(NUM)
C      *****NOW WE KNOW THE PARENT AND BRANCHING VARIABLE FOR THE NEXT
C      *****STAGE--SET UP 2 OR 3 NEW PROBLEMS
C      *****FILL KL AND KR VECTORS
            DO 5070 I=1,NUMVAR
            KR(I)=KRO(I)
 5070       KL(I)=KLO(I)
      ZNBACK=ZLSTNO(NUM)
            DO 5080 I=1,NUM
            II=NUM-I+1
            IF(ZNBACK.EQ.0.0)GO TO 5110
            IF(ZLSTNO(II).NE.ZNBACK)GO TO 5080
                  DO 5090 IK=1,NUM
                  IF(ZLSTNO(IK).EQ.ZLSTPA(II))GO TO 5095
```

```
 5090          CONTINUE
 5095       III=IBRVR(IK)
            IF(.NOT.((LSTKL(II).GE.KL(III)).AND.(LSTKR(II).LE.KR(III))))
     1      GO TO 5100
            KL(III)=LSTKL(II)
            KR(III)=LSTKR(II)
 5100       ZNBACK=ZLSTBA(II)
 5080       CONTINUE
 5110 CONTINUE
C     *****NOW HAVE TO DIVIDE UP THE K-SET FOR THE BRANCHING VARIABLE
C     *****BUT FIRST, REMOVE THE PARENT PROBLEM FROM THE LIST
      ZLSLB(NUM)=1.E70
C     *****SET UP TWO OR THREE PROBLEMS
      IF((FLAG(NUM).LT.KL(IBRPAR)).OR.(FLAG(NUM).GT.KR(IBRPAR)))
     1CALL ERR(11)
C     *****CHECK TO SEE IF FLAG PRECISELY EQUALS SOME CUT
            IW=KL(IBRPAR)
            IZ=KR(IBRPAR)
            DO 5120 J=IW,IZ
            ZJ=J
            XXX=ZJ-FLAG(NUM)
            XXX=ABS(XXX)
            IF(XXX.LE.CUTTOL)GO TO 5130
 5120       CONTINUE
      IX=FLAG(NUM)
      IF(IX.EQ.KL(IBRPAR))GO TO 5140
      KBL(1)=KL(IBRPAR)
      KBR(1)=IX
      KBL(2)=IX
      KBR(2)=IX+1
      IF((IX+1).EQ.KR(IBRPAR))5150,5160
 5150 NOLFT=2
      GO TO 6000
 5160 KBL(3)=IX+1
      KBR(3)=KR(IBRPAR)
      NOLFT=3
      GO TO 6000
 5140 KBL(1)=IX
      KBR(1)=IX+1
      KBL(2)=IX+1
      KBR(2)=KR(IBRPAR)
      NOLFT=2
      GO TO 6000
 5130 IF((J.EQ.KL(IBRPAR)).OR.(J.EQ.KR(IBRPAR)))CALL ERR(10)
      KBL(1)=KL(IBRPAR)
      KBR(1)=J
      KBL(2)=J
      KBR(2)=KR(IBRPAR)
      NOLFT=2
 6000 IXX=STGPRB
      STGPRB=IXX
      STGPRB=STGPRB+1.
      GO TO 5000
C     *****DONE-- PRINT OUT THE RESULTS
 8000 CONTINUE
 8010 FORMAT(1H1,8A10)
      PRINT 8020,BLB
 8020 FORMAT(1H0,31HOBJECTIVE FUNCTION AT OPTIMUM  ,G12.4)
```

```
      TCOSTS=TCOSTS+BUB
      PRINT 8025,TCOSTS
8025  FORMAT(1H0,/*    TOTAL DISCOUNTED COSTS= *,F10.3/)
      PRINT 8030
8030  FORMAT(1H0,28HVARIABLE VALUES AT OPTIMUM--)
      CALL XPRINT(XBEST)
      END
```

```
      SUBROUTINE XPRINT(Z)
      COMMON        KLO(840),KRO(840),KL(840),KR(840),XCODED(840),XREST
     1(840),W(840),CUTS(840),ZLSTNO(5),ZLSTPA(5),LSTKL(5),LSTKR(5),
     2ZLSLB(5),IBRVR(5),FLAG(5),KBL(3),KBR(3),VARNAM(1),PROBNA(1),
     3MAXVAR,MAXCUT,LSTMAX,MAXROW,MAXA,NMROWS,NUMVAR,ICHK(430),VAL,LFLG,
     4ISTEP,LWH1,LWH2,KW1,KW2,KH1,KH2
      DIMENSION W1(36),W2(36),H1(36),H2(36),TWH1(36),TWH2(36),PROD(36)
C
      DIMENSION Z(1)
      REAL KW1,KW2,KH1,KH2
C
      PRINT 10
 10   FORMAT(1H0)
      PRINT 20
   20 FORMAT(1H-,*  BUILD-UP PERIOD *50(1H*))
      I1= 6+23*ISTEP
      I2=7+23*ISTEP
      PRINT 115,Z(I1),Z(I2)
  115 FORMAT(1H0,*IBW1= *F12.3,3X*IHW2= *F12.3)
      PRINT 110,Z(1),Z(2),Z(3),Z(4)
 110  FORMAT(1H0,*BC1= *F12.3,3X,*BC2= *F12.3,3X,*BW1= *F12.3,3X*BW2= *
     1F12.3)
      A=Z(5)-Z(6)
      B=Z(7)-Z(8)
      C=Z(9)-Z(10)
      D=Z(11)-Z(12)
      PRINT 120,A,B,C,D
 120  FORMAT(1H0,*SLOPEC1= *F12.3,3X*SLOPEC2= *F12.3,3X*SLOPEW1= *F12.3,
     13X,*SLOPEW2= *F12.3)
      PRINT 125
  125 FORMAT(1H-,*  STEADY-STATE PERIOD *50(1H*))
      TOTCAP=Z(13)+Z(14)+Z(15)+Z(16)
      PRINT 130,Z(13),Z(14),Z(15),Z(16),TOTCAP
  130 FORMAT(1H0,*EC1= *F12.3,3X*EC2= *F12.3,3X*EW1= *F12.3,3X*EW2= *F12
     1.3,3X*TOTAL CAPITAL= *,F12.3)
      PRINT 140,Z(17),Z(18)
 140  FORMAT(1H0,*ES= *F12.3,3X*EPREP= *F12.3)
      XRATIO=TOTCAP/Z(17)
      PRINT 141,XRATIO
  141 FORMAT(1H0,*  BASE/STOCKPILE RATIO= *F7.3)
      PRINT 142
  142 FORMAT(1H-,*  WARTIME PERIOD *50(1H*))
      PRINT 10
      DO 150 I=1,ISTEP
      I1=I+18
      I2=I+18+ISTEP
      I3=I+18+2*ISTEP
      I4=I+18+3*ISTEP
      I5=I+18+4*ISTEP
      W1(I)=Z(I3)
      W2(I)=Z(I4)
      H1(I)=Z(I5)
  150 PRINT 145,I,Z(I1),I,Z(I2),I,Z(I3),I,Z(I4),I,Z(I5)
  145 FORMAT(1H ,*C1(*I2*)=*F12.3,6X,*C2(*I2*)=*F12.3,6X*W1(*I2*)=*F12.3
     1,6X*W2(*I2*)=*F12.3,6X*H1(*I2*)=*F12.3)
      DO 160 I=1,ISTEP
      I1=I+18+5*ISTEP
```

```
      I2=I+18+6*ISTEP
      I3=I+18+7*ISTEP
      I4=I+18+8*ISTEP
      I5=I+18+9*ISTEP
      H2(I)=Z(I1)
  160 PRINT 165,I,Z(I1),I,Z(I2),I,Z(I3),I,Z(I4),I,Z(I5)
  165 FORMAT(1H ,*H2(*I2*)=*F12.3,6X*PC1(*I2*)=*F12.3,5X*PC2(*I2*)=*F12.
     13,5X*S(*I2*)=*F12.3,7X*SP(*I2*)=*F12.3)
      II=ISTEP-1
      DO 170 I=1,II
      I1=I+18+10*ISTEP
      I2=I+17+11*ISTEP
      I3=I+16+12*ISTEP
      I4=I+15+13*ISTEP
      I5=I+14+14*ISTEP
  170 PRINT 175,I,Z(I1),I,Z(I2),I,Z(I3),I,Z(I4),I,Z(I5)
  175 FORMAT(1H ,*PIPE(*I2*)=*F12.3,4X*TCW1(*I2*)=*F12.3,4X*TCW2(*I2*)=*
     1F12.3,4X*TCH1(*I2*)=*F12.3,4X*TCH2(*I2*)=*F12.3)
      DO 180 I=1,II
      I1=I+13+15*ISTEP
      I2=I+12+16*ISTEP
      I3=I+11+17*ISTEP
      I4=I+10+18*ISTEP
      I5=I+9+19*ISTEP
      TWH1(I)=Z(I1)
      TWH2(I)=Z(I2)
  180 PRINT 185,I,Z(I1),I,Z(I2),I,Z(I3),I,Z(I4),I,Z(I5)
  185 FORMAT(1H ,*TWH1(*I2*)=*F12.3,4X*TWH2(*I2*)=*F12.3,4X*TWC1(*I2*)=*
     1F12.3,4X*TWC2(*I2*)=*F12.3,4X*THC1(*I2*)=*F12.3)
      DO 190 I=1,II
      I1=I+8+20*ISTEP
      I2=I +7+21*ISTEP
      I3=I +6+22*ISTEP
  190 PRINT 195,I,Z(I1),I,Z(I2),I,Z(I3)
  195 FORMAT(1H ,*THC2(*I2*)=*F12.3,4X*THW1(*I2*)=*F12.3,4X*THW2(*I2*)=*
     1F12.3)
C
C          PRINT OUT PRODUCTION CURVE
C
      DO 300 I=1,ISTEP
      I71=LWH1
      I72=LWH2
      IF (I71.GT.I) I71=I
      IF (I72.GT.I) I72=I
      SMTWH1=0.
      DO 201  J=1,I71
      SMTWH1=SMTWH1+TWH1(I-J+1)
  201 CONTINUE
      SMTWH2=0.
      DO 202 J=1,I72
      SMTWH2=SMTWH2+TWH2(I-J+1)
  202 CONTINUE
C
      XX1=(SMTWH1+W1(I))/KW1
      XX2=(SMTWH2+W2(I))/KW2
      XX3=H1(I)/KH1
      XX4=H2(I)/KH2
      PROD(I)=XX1+XX2+XX3+XX4
```

```
  300 CONTINUE
C
      PRINT 310
  310 FORMAT(1H ,//*    WARTIME PRODUCTION CURVE */)
      XSUM=0.
      DO 320 I=1,ISTEP
      XSUM=XSUM+PROD(I)
      PRINT 315,I,PROD(I)
  315 FORMAT(1H ,*PRODUCTION(*I2*)=*F12.3)
  320 CONTINUE
      PRINT 330,XSUM
  330 FORMAT(1H-,*    TOTAL WARTIME PRODUCTION= *,F10.3)
      PRINT 10
      RETURN
      END
```

```
      SUBROUTINE LPPR(Y)
      COMMON        KLD(840),KRO(840),KL(840),KH(840),XCODED(840),XREST
     1(840),W(840),CUTS(840),ZLSTNO(5),ZLSTPA(5),LSTKL(5),LSTKR(5),
     2ZLSLB(5),IBRVR(5),FLAG(5),KBL(3),KBR(3),VARNAM(1),PROBNA(1),
     3MAXVAR,MAXCUT,LSTMAX,MAXROW,MAXA,NMROWS,NUMVAR,ICHK(430),VAL,LFLG,
     4ISTEP,LWH1,LWH2,KW1,KW2,KH1,KH2
      DIMENSION Y(1)
      PRINT 10
   10 FORMAT(1H0,29HPACKED LP SOLUTION, I     X(I))
            IW=KRO(NUMVAR)
            DO 30 I=1,IW
      IF(ABS(Y(I)).GE.1.E-10)PRINT 20,I,Y(I)
   20       FORMAT(1H ,15X,I6,2X,G10.4)
   30       CONTINUE
      PRINT 40
   40 FORMAT(1H0)
      RETURN
      END
```

```
      SUBROUTINE ERR(I)
      PRINT100
100   FORMAT(*1PROGRAM MOGG ABORTED BECAUSE....*)
      GOTO(101,102,103,104,105,106,107,108,109,110,111),I
101   PRINT 201
      CALL EXIT
102   PRINT 202
      CALL EXIT
103   PRINT 203
      CALL EXIT
104   PRINT 204
      CALL EXIT
105   PRINT 205
      CALL EXIT
106   PRINT 206
      CALL EXIT
107   PRINT 207
      CALL EXIT
108   PRINT 208
      CALL EXIT
109   PRINT 209
      CALL EXIT
110   PRINT 210
      CALL EXIT
111   PRINT 211
      CALL EXIT
      RETURN
201   FORMAT(*0VARIABLE CARDS OUT OF ORDER--LOOK NEAR MOGG LABEL 105*)
202   FORMAT(*0MAXCUTS EXCEEDED--LOOK NEAR MOGG LABEL 117 OR 124*)
203   FORMAT(*0MATRIX A EXCEEDED--LOOK NEAR MOGG LABEL 9400*)
204   FORMAT(*0LPMAX EXCEEDED--LOOK NEAR MOGG LABEL 1005*)
205   FORMAT(*0INITIAL LP INFEASIBLE--LOOK NEAR MOGG LABEL 1008*)
206   FORMAT(*0LIST LENGTH EXCEEDED--LOOK NEAR MOGG LABEL 1020*)
207   FORMAT(*0XCODED VIOLATES CUTS--LOOK NEAR MOGG LABEL 1060 OR 7025*)
208   FORMAT(*0NO BRANCHING NODE FOUND--LOOK NEAR MOGG LABEL 5060*)
209   FORMAT(*0NO FEASIBLE POINT FOUND--LOOK NEAR MOGG LABEL 5064*)
210   FORMAT(*0NO BRANCHING POSSIBLE ON VARIABLE CHOSEN--LOOK NEAR MOGG
     1LABEL 5130*)
211   FORMAT(*0FLAG COMPUTED IMPROPERLY--LOOK NEAR MOGG LABEL 5110*)
      END
```

```
      SUBROUTINE SCAII
      COMMON       KLO(840),KRO(840),KL(840),KR(840),XCODED(840),XBEST
     1(840),W(840),CUTS(840),ZLSTNO(5),ZLSTPA(5),LSTKL(5),LSTKR(5),
     2ZLSLB(5),IBRVR(5),FLAG(5),KBL(3),KBR(3),VARNAM(1),PROBNA(1),
     3MAXVAR,MAXCUT,LSTMAX,MAXROW,MAXA,NMROWS,NUMVAR,ICHK(430),VAL,LFLG,
     4ISTEP,LWH1,LWH2,KW1,KW2,KH1,KH2
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVFRQ,IOBJ,IROWP,ITCH,ITCHA,ITCNT,ITRFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NELEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QFC,QBL,QPL,QMI,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FD(36),UPSP(36),URPIPE(36)
      DO 100 IXX=2,NMROWS
      SMALL=1.E70
      BIG=-1.E70
      LAST=LA(NCOL+1)-1
      IFIRST=LA(NROW+1)
      DO 200 IXY=IFIRST,LAST
      IF(IA(IXY).NE.IXX)GOTO200
      IF(ABS(A(IXY)).LT.SMALL)SMALL=ABS(A(IXY))
      IF(ABS(A(IXY)).GT.BIG)BIG=ABS(A(IXY))
  200 CONTINUE
      AV=SQRT(SMALL*BIG)
      ZL2AV=ALOG(AV)/ALOG(2.)
      L2AV=INT(ZL2AV)
      IF(ZL2AV.LT.0..AND.L2AV-ZL2AV.GE..5)L2AV=L2AV-1
      IF(ZL2AV.GT.0..AND.ZL2AV-L2AV.GE..5)L2AV=L2AV+1
      DIV=2.**L2AV
      DO 300 IXY=IFIRST,LAST
      IF(IA(IXY).NE.IXX)GOTO300
      A(IXY)=A(IXY)/DIV
  300 CONTINUE
      B(IXX)=B(IXX)/DIV
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LINPRG
C
      COMMON        KLO(840),KRO(840),KL(840),KR(840),XCODED(840),XBEST
     1(840),W(840),CUTS(840),ZLSTNO(5),ZLSTPA(5),LSTKL(5),LSTKR(5),
     2ZLSLB(5),IBRVR(5),FLAG(5),KBL(3),KBR(3),VARNAM(1),PROBNA(1),
     3MAXVAR,MAXCUT,LSTMAX,MAXROW,MAXA,NMROWS,NUMVAR,ICHK(430),VAL,LFLG,
     4ISTEP,LWH1,LWH2,KW1,KW2,KH1,KH2
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVFRQ,IOBJ,IROWP,ITCH,ITCHA,ITCNT,ITRFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NELEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QFC,QBL,QPL,QMI,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FD(36),URSP(36),URPIPE(36)
C
C
C
      ITCNT=0
      ITCHA=0
C        SET UP STARTING BASIS
      DO 9100 J=1,NCOL
 9100 KINBAS(J)=0
      DO 900 I=1,NROW
      ICOL=JH(I)
      ML=NROW
           DO 300 K=1,NUMVAR
           MR=KL(K)+NROW
           IF((ICOL.GT.ML).AND.(ICOL.LT.MR))GO TO 700
           ML=KR(K)+NROW
 300       CONTINUE
      IF(ICOL.GT.ML)GO TO 700
      GO TO 900
 700  JH(I)=I
 900  CONTINUE
C
C
 1000 CALL INVERT
      ITSINV = 0
      CALL ITEROP(0)
C
C                      SIMPLEX CYCLE
C
 1500 CALL FORMC
      CALL SHIFTR(3,4)
      ITCH=0
 1700 CALL BTRAN
      CALL PRICE
      IF (CMIN .LE.-ZTCOST) GO TO 3000
      IF (XSTAT .EQ. QI    ) GO TO 2000
      XSTAT = QBL
      GO TO 6000
 2000 XSTAT=QN
      GO TO 6000
 3000 CALL UNPACK(JCOLP)
      CALL FTRAN(1)
```

```
      ERMAX=0.
      DO 8000 I=1,NROW
      ERMAX=ERMAX+Y(I)*YTEMP(I)
 8000 CONTINUE
      DIFXX=CMIN-ERMAX
      DIFXX=ABS(DIFXX)
      IF (DIFXX.LE.ZTCOST)  GO TO 8500
      IF (K3.NE.1)  GO TO 8100
      PRINT 9500,CMIN,ERMAX
 9500 FORMAT(1H ,10X,6HCMIN= ,F16.8,5X,7HERMAX= ,F16.8)
 8100 IF (ERMAX.LE.0.)  GO TO 8500
      IF (ITCH.GT.0)  GO TO 1000
      ITCH=JCOLP
      ITCHA=ITCHA+1
      CALL SHIFTR(4,3)
      GO TO 1700
 8500 CONTINUE
      CALL CHUZR
      IF(XSTAT.EQ.GU)GO TO 6000
      IVOUT=JH(IROWP)
      IVIN = JCOLP
      CALL URETA
      KINBAS(JCOLP) = IROWP
      KINBAS(IVOUT) = 0
      JH(IROWP) = IVIN
      ITCNT = ITCNT + 1
      ITSINV = ITSINV + 1
      CALL IIEROF(1)
      IF (NELEM.GT.5500) GO TO 1000
      CALL WRETA
      IF (ITSINV .GE. INVERQ) GO TO 1000
      IF (ITCNT .GE. ITPERQ) GO TO 6000
      GO TO 1500
C
 6000 CALL ITEROF(1)
C
C        SET PARMS
C
      DO 7000 I=1,NROW
      JHX=JH(I)
      IF (JHX.LE.NROW)  GO TO 6500
       W(JHX-NROW)=X(I)
 6500 CONTINUE
 7000 CONTINUE
C
C
      VAL=-X(IOBJ)
      LFLG=1
      IF (XSTAT.EQ.QBL)  LFLG=0
      PRINT 9600,ITCHA
 9600 FORMAT(1H+,108X,18HSTABILITY COUNT = ,I5)
 7100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FORMC
C
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVFRQ,IOBJ,IPOWR,ITCH,ITCHA,ITCNT,ITHFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NELEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QFC,QBL,QPL,QMI,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FU(36),UPSP(36),UBPIPE(36)
C
C
      XSTAT=QE
      IFFEZ = 1
      DO 100 I = 1,NROW
      Y(I) = 0.
  100 CONTINUE
      SUM = 0.
C
      DO 1000 I = 1,NROW
      ICOL = JH(I)
      IF (ICOL .GT. NROW) GO TO 500
      IF (ISTYPE(ICOL)) 200,1000,500
C
  200 IF ( ABS(X(I)) .LE. ZTOLZE) GO TO 1000
      IF(X(I) .LT. 0.) Y(I) = +1.
      IF(X(I) .GT. 0.) Y(I) = -1.
      SUM = SUM +  ABS(X(I))
      GO TO 510
C
  500 IF(X(I) .GT. -ZTOLZE) GO TO 1000
      Y(I) = +1.
      SUM = SUM - X(I)
  510 IFFEZ = 0
      XSTAT = QI
 1000 CONTINUE
C
      SUMINF = SUM
      IF (IFFEZ .LE. 0) GO TO 9000
      Y(IOBJ) = 1.
C
 9000 RETURN
      END
```

```
      SUBROUTINE BTRAN
C
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVFRQ,IOBJ,IROWP,ITCH,ITCHA,ITCNT,ITHFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NELEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1   QFI,QFC,QBL,QPL,QMI,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FD(36),UBSP(36),UBPIPE(36)
C
      IF (NETA .LE. 0) GO TO 9000
      DO 1000 I = 1,NETA
      IK = NETA - I + 1
      LL = LE(IK)
      KK = LE(IK+1) - 1
      IPIV = IE(LL)
      DP = E(LL)
      DY = Y(IPIV)
      DSUM = 0.
      IF (KK .LE. LL) GO TO 600
      LL = LL + 1
      DO 500 J = LL,KK
      IR = IE(J)
      DE = E(J)
      DPROD = DE * Y(IR)
      DSUM = DSUM + DPROD
  500 CONTINUE
C
  600 Y(IPIV) = (DY - DSUM) / DP
 1000 CONTINUE
C
 9000 RETURN
      END
```

```
      SUBROUTINE PRICE
C
      COMMON       KLO(840),KRO(840),KL(840),KR(840),XCODED(840),XBEST
     1(840),W(840),CUTS(840),ZLSTNO(5),ZLSTPA(5),LSTKL(5),LSTKR(5),
     2ZLSLB(5),IBRVR(5),FLAG(5),KBL(3),KBR(3),VARNAM(1),PROBNA(1),
     3MAXVAR,MAXCUT,LSTMAX,MAXROW,MAXA,NMROWS,NUMVAR,ICHK(430),VAL,LFLG,
     4ISTEP,LWH1,LWH2,KW1,KW2,KH1,KH2
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,FRMAX,IFFEZ,
     3  INVFRQ,IOBJ,IROWP,ITCH,ITCHA,ITCNT,ITRFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NELEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QFC,QBL,QPL,QMI,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FD(36),UBSP(36),UBPIPE(36)
C
      JCOLP = 0
      CMIN = 1.E10
      DO 1000 J = 1,NCOL
      IF(J .LE. NROW .AND. ISTYPE(J) .NE. 1) GO TO 1000
      IF (KINBAS(J) .NE. 0) GO TO 1000
      IF (ITCH.EQ.J)  GO TO 1000
C
      DSUM = 0.
      LL = LA(J)
      KK = LA(J+1) - 1
      DO 500 I = LL,KK
      IR = IA(I)
      DE = A(I)
      DPROD = DE * Y(IR)
      DSUM = DSUM + DPROD
  500 CONTINUE
      IF (DSUM .GE. CMIN) GO TO 1000
      CMIN = DSUM
      JCOLP = J
 1000 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SHIFTR(IOLD,INEW)
C
      COMMON/WORK1/B(430),X(430),Y(430),VTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVFRQ,IOBJ,IROWP,ITCH,ITCHA,ITCNT,ITRFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NELEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QEC,QBL,QPL,QMI,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FU(36),UBSP(36),UBPIPE(36)
C
      DIMENSION BARRAY(1400)
      EQUIVALENCE (BARRAY(1),B(1))
C
      IFO = (IOLD - 1) * NRMAX
      IFN = (INEW- 1) * NRMAX
C
      DO 1000 I = 1,NROW
      BARRAY(IFN + I) = BARRAY(IFO + I)
 1000 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE UNPACK(IV)
C
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVERQ,IOBJ,IPOWR,ITCH,ITCHA,ITCNT,ITHERO,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NFLEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUFLEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QFC,QBL,QPL,QMI,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FD(36),URSP(36),URPIPE(36)
C
      DO 100 I = 1,NROW
      Y(I) = 0.
  100 CONTINUE
C
      LL = LA(IV)
      KK = LA(IV+1) - 1
      DO 200 I = LL,KK
      IR = IA(I)
      Y(IR) = A(I)
  200 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE FTRAN(IPAR)
C
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVFRQ,IOBJ,IROWP,ITCH,ITCHA,ITCNT,ITRFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NELEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QEC,QBL,QPL,QMI,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FU(36),UBSP(36),UBPIPE(36)
C
      GO TO (100,110),IPAR
  100 NFE = 1
      NLE = NETA
      GO TO 200
  110 NFE = NLETA + 1
      NLE = NETA
  200 IF (NFE .GT. NLE) GO TO 9000
      DO 1000 IK = NFE,NLE
      LL = LE(IK)
      KK = LE(IK+1)  - 1
      IPIV = IE(LL)
      DY = Y(IPIV)
      DY = DY/E(LL)
      Y(IPIV) = DY
      IF (KK .LE. LL) GO TO 1000
      LL = LL + 1
      DO 500 J = LL,KK
      IR = IE(J)
      Y(IR) = Y(IR) - E(J) * DY
  500 CONTINUE
 1000 CONTINUE
 9000 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CHUZR
C
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVFRQ,IOBJ,IROWP,ITCH,ITCHA,ITCNT,ITRFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NELEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QET,QEC,QBL,QPL,QMT,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),OD(36),FD(36),URSP(36),URPIPE(36)
C
C          SELECT PIVOT ROW/VARIABLE TO LEAVE THE BASIS
C
      ZTOLCH=1.E-5
      ZTOLXX=1.E-10
      XMIN1=1.E10
      XMIN2=1.E10
      XMIN3=1.E10
      IROWP1=0
      IROWP2=0
      IROWP3=0
C
      DO 2000 I=1,NROW
      IF (ISTYPE(I).EQ.0)  GO TO 2000
      IF (ABS(Y(I)).LT.ZTOLCH)  GO TO 2000
      ICOL=JH(I)
      IF ((ICOL.LE.NROW).AND.(ISTYPE(I).LT.0))  GO TO 1000
      XRATIO=X(I)/Y(I)
      IF(XRATIO.LT.-ZTOLZE)GOTO2000
      IF(Y(I).LT.0.)GOTO2000
      IF (XRATIO.GT.XMIN1)  GO TO 2000
      XMIN1=XRATIO
      IROWP1=I
      GO TO 2000
C
 1000 IF (ABS(X(I)).LT.ZTOLZE)  GO TO 1500
      XRATIO=X(I)/Y(I)
      IF (XRATIO.LT.0.)  GO TO 2000
      IF (XRATIO.GT.XMIN2)  GO TO 2000
      XMIN2=XRATIO
      IROWP2=I
      GO TO 2000
C
 1500 XXX=ABS(Y(I))
      XRATIO=ZTOLXX/XXX
      IF (XRATIO.GT.XMIN3)  GO TO 2000
      XMIN3=XRATIO
      IROWP3=I
C
 2000 CONTINUE
C
C          TEST FOR OUTGOING VECTOR
C
      IROWP=IROWP1
      XRATIO=XMIN1
      IF (XRATIO.LE.XMIN2)  GO TO 3000
```

```
      IROWP=IROWP2
      XRATIO=XMIN2
C
 3000 IF (XRATIO.LE.XMIN3)  GO TO 4000
      IROWP=IROWP3
      XRATIO=XMIN3
C
 4000 IF (IROWP.LE.0)  XSTAT=QU
      I=IROWP
      IF (K3.NE.1)  RETURN
      PRINT 9000,IROWP,X(I),Y(I),JH(I)
 9000 FORMAT(8H IROWP= ,I4,2X,6HX(I)= ,F16.8,2X,6HY(I)= ,F16.8,2X
     1,7HJH(I)= ,I4)
      RETURN
      END
```

```
      SUBROUTINE UPBETA
C
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVFRQ,IOBJ,IROWP,ITCH,ITCHA,ITCNT,ITHFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NFLEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUFLEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QFC,QBL,QPL,QMI,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FU(36),UBSP(36),UBPIPE(36)
C
      DE = X(IROWP)
      DP = DE/Y(IROWP)
      X(IROWP) = DP
      DO 1000 I = 1,NROW
      IF (I .EQ. IROWP) GO TO 1000
      DE = X(I)
      X(I) = DE - Y(I)*DP
 1000 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE WRETA
C
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVFRQ,IOBJ,IROWP,ITCH,ITCHA,ITCNT,ITRFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NELEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QFC,QBL,QPL,QMI,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FD(36),URSP(36),URPIPE(36)
C
      NELEM = NELEM + 1
      IE(NELEM) = IROWP
      E(NELEM) = Y(IROWP)
C
      DO 1000 I = 1,NROW
      IF (I .EQ. IROWP) GO TO 1000
      IF ( ABS(Y(I)) .LE. ZTOLZE) GO TO 1000
      NELEM = NELEM + 1
      IE(NELEM) = I
      E(NELEM) = Y(I)
 1000 CONTINUE
C
      NETA = NETA + 1
      LE(NETA+1) = NELEM + 1
      RETURN
      END
```

```
      SUBROUTINE ITEROP(IPAR)
C
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVFRQ,IOBJ,IPOWP,ITCH,ITCHA,ITCNT,ITHFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NELEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QFC,QBL,QPL,QMI,QA,QB,QC,QF,QE,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FD(36),UPSP(36),URPIPE(36)
C
      IF (IPAR .EQ.0) GO TO 1000
      OBJ =-X(IOBJ)
      IF (IFFEZ .EQ. 0) OBJ = SUMINF
C
      IF(K3.NE.1)RETURN
      WRITE(6,8000) ITCNT,XSTAT,OBJ,IVIN,IVOUT,CMIN,
     1NETA,NELEM,TIMER
 8000 FORMAT(1H ,I5,4XA4,2X,F16.8,4X,I6,4X,I6,4X,F16.8,4X,I6,I8,
     1F8.2  )
      GO TO 9000
 1000 IF(K3.NE.1)RETURN
      WRITE(6,8100)
 8100 FORMAT(//8H0ITCOUNT,2X6HSTATUS,4X9HOBJ VALUE,8X,5HVECIN,5X6HVECOUT
     1,11X,2HQJ,12X,4HNETA,3X,5HNELEM,4X,4HTIME )
 9000 RETURN
      END
```

```
      SUBROUTINE INVERT
C
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVERQ,IOBJ,IROWP,ITCH,ITCHA,ITCNT,ITHFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NELEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QFC,QBL,QPL,QMI,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FD(36),UPSP(36),UBPIPE(36)
C
      INTEGER    MREG,HREG,VREG
      DIMENSION MREG(430),HREG(430),VREG(430)
      EQUIVALENCE (MREG,YTEMP),(HREG,X)
C
C          SET PARAMETERS
C
      NETA = 0
      NLETA = 0
      NGETA = 0
      NUETA = 0
      NELEM = 0
      NLELEM = 0
      NGELEM = 0
      NUELEM = 0
      NABOVE = 0
      LE(1) = 1
      LP1 = 1
      KP1 = 0
      LP4 = NROW + 1
      KP4 = NROW
C
C          PUT SLACKS AND ARTIFICIALS IN PART 4 AND REST IN PART 1
C
      DO 100 I = 1,NROW
      IF (JH(I) .GT. NROW) GO TO 50
      LP4 = LP4 - 1
      MREG(LP4) = JH(I)
      VREG(LP4) = JH(I)
      GO TO 90
   50 KP1 = KP1 + 1
      VREG(KP1) = JH(I)
   90 HREG(I) = -1
      JH(I) = 0
  100 CONTINUE
C
      KP3 = LP4 -1
      LP3 = LP4
C
      DO 200 I = LP4,KP4
      IR = MREG(I)
      HREG(IR)= 0
      JH(IR) = IR
      KINBAS(IR) = IR
  200 CONTINUE
C
```

```
C                         PULL OUT VECTORS BELOW BUMP AND GET ROW COUNTS
C
      NBNONZ = KR4 - LR4 + 1
      IF (KR1 .EQ. 0) GO TO 1190
      J = LR1
  210 IV = VREG(J)
      LL = LA(IV)
      KK = LA(IV+1) -1
      IRCNT = 0
      DO 220 I = LL,KK
      NBNONZ = NBNONZ + 1
      IR = IA(I)
      IF (HREG(IR) .GE. 0) GO TO 220
      IRCNT = IRCNT + 1
      HREG(IR) = HREG(IR) - 1
      IRP = IR
  220 CONTINUE
      IF(IRCNT - 1) 230,250,300
  230 CONTINUE
      IF(K3.EQ.1)PRINT 8000
 8000 FORMAT(16HOMATRIX SINGULAR )
      KINBAS(IV) = 0
      VREG(J) = VREG(KR1)
      KR1 = KR1 - 1
      IF (J .GT. KR1) GO TO 310
      GO TO 210
C
  250 VREG(J) = VREG(KR1)
      KR1 = KR1 - 1
      LR3 = LR3 - 1
      VREG(LR3) = IV
      MREG(LR3) = IRP
      HREG(IRP) = 0
      JH(IRP) = IV
      KINBAS(IV) = IRP
      IF (J .GT. KR1) GO TO 310
      GO TO 210
  300 IF (J .GE. KR1) GO TO 310
      J = J+1
      GO TO 210
C
C                         PULL OUT REMAINING VECTORS ABOVE AND BELOW THE
C                         BUMP AND ESTABLISH MERIT COUNTS OF COLUMNS
C
  310 NVREM = 0
      IF(KR1 .EQ. 0) GO TO 1190
      J = LR1
  320 IV = VREG(J)
      LL = LA(IV)
      KK = LA(IV+1) - 1
      IRCNT = 0
      DO 800 I = LL,KK
      IR = IA(I)
      IF(HREG(IR) .NE. -2) GO TO 400
C
C         PIVOT ABOVE BUMP (PART OF L)
C
      NABOVE = NABOVE + 1
```

```
      IRCWP = IR
      CALL UNPACK(IV)
      CALL WHETA
      NLETA = NETA
      JH(IR) = IV
      KINBAS(IV) = IR
      VREG(J) = VREG(KR1)
      KR1 = KR1 - 1
      NVREM = NVREM + 1
      HREG(IR) = IV
      GO TO 940
C
  400 IF (HREG(IR) .GE. 0) GO TO 800
      IRCNT = IRCNT + 1
      IRR = IR
  800 CONTINUE
C
      IF (IRCNT - 1) 810,900,1000
 810  CONTINUE
      IF(K3.EQ.1)PRINT 8000
      KINBAS(IV) = 0
      VREG(J) = VREG(KR1)
      NVREM = NVREM + 1
      KR1 = KR1 - 1
      IF (J .GT. KR1) GO TO 1010
      GO TO 320
C
C                         PUT VECTOR BELOW BUMP
C
  900 VREG(J) = VREG(KR1)
      NVREM = NVREM + 1
      KR1 = KR1 - 1
      LR3= LR3 - 1
      VREG(LR3) = IV
      MREG(LR3) = IRR
      HREG(IRR) = 0
      JH(IRR) = IV
      KINBAS(IV) = IRR
C
C                         CHANGE ROW COUNTS
C
  940 DO 950 II = LL,KK
      IIR = IA(II)
      IF (HREG(IIR) .GE. 0) GO TO 950
      HREG(IIR) = HREG(IIR) + 1
  950 CONTINUE
      IF (J .GT. KR1) GO TO 1010
      GO TO 320
 1000 IF (J .GE. KR1) GO TO 1010
      J = J+1
      GO TO 320
 1010 IF (NVREM .GT. 0)  GO TO 310
C
C                         GET MERIT COUNTS
C
 1020 IF (KR1 .EQ. 0)  GO TO 1190
      DO 1100 J = LR1,KR1
      IV = VREG(J)
```

```
      LL = LA(IV)
      KK = LA(IV+1) - 1
      IMCNT = 0
      DO 1050 I = LL,KK
      IR = IA(I)
      IF (HREG(IR) .GE. 0) GO TO 1050
      IMCNT = IMCNT - (HREG(IR) +1)
 1050 CONTINUE
      MREG(J) = IMCNT
 1100 CONTINUE
C
C                     SORT COLUMNS INTO MERIT ORDER
C                     USING SHELL SORT
C
      ISD = 1
 1106 IF (KR1 .LT. 2*ISD) GO TO 1108
      ISD = 2*ISD
      GO TO 1106
 1108 ISD = ISD - 1
C                     END OF INITIALIZATION
 1101 IF (ISD .LE. 0) GO TO 1107
      ISK = 1
 1102 ISJ = ISK
      ISL = ISK + ISD
      ISY = MREG(ISL)
      ISZ = VREG(ISL)
 1103 IF (ISY .LT. MREG(ISJ)) GO TO 1104
 1105 ISL = ISJ + ISD
      MREG(ISL) = ISY
      VREG(ISL) = ISZ
      ISK = ISK + 1
      IF ((ISK + ISD) .LE. KR1) GO TO 1102
      ISD = (ISD - 1) / 2
      GO TO 1101
 1104 ISL = ISJ + ISD
      MREG(ISL) = MREG(ISJ)
      VREG(ISL) = VREG(ISJ)
      ISJ = ISJ - ISD
      IF (ISJ .GT. 0) GO TO 1103
      GO TO 1105
 1107 CONTINUE
C                     END OF SORT ROUTINE
C
C                     PUT OUT BELOW BUMP ETAS (PART OF U)
C
 1198 NSLCK = 0
      NBELOW = 0
      NELAST = NEMAX
      NTLAST = NTMAX
      LE(NTLAST + 1) = NELAST + 1
C
      LR = LR3
      IF (LR3 .GE. LR4) LR = LR4
      IF (LR .GT. KR4) GO TO 2050
      JK = KR4 + 1
      DO 2000 JJ=LR,KR4
      JK = JK - 1
      IV = VREG(JK)
```

```
      I = MREG(JK)
      NBELOW = NBELOW + 1
      IF (IV .GT. NROW) GO TO 1200
      NSLCK = NSLCK + 1
 1200 LL = LA(IV)
      KK = LA(IV+1) -1
      IF (KK .GT. LL) GO TO 1300
 1250 IF (ABS(A(LL) - 1.) .LE. ZTOLZE) GO TO 2000
C
 1300 NUETA = NUETA + 1
      DO 1400 J = LL,KK
      IP = IA(J)
      IF (IP .EQ. I) GO TO 1390
      IF(NELAST)=IP
      E(NELAST) = A(J)
      NELAST = NELAST - 1
      NUELEM = NUELEM + 1
      GO TO 1400
 1390 EP = A(J)
 1400 CONTINUE
      IF(NELAST) = I
      E(NELAST) = EP
      LE(NTLAST) = NELAST
      NELAST = NELAST - 1
      NTLAST = NTLAST - 1
      NUELEM = NUELEM + 1
 2000 CONTINUE
 2050 IF(KB1 .EQ. 0) GO TO 3500
C
C                       DO L-U DECOMPOSITION OF BUMP
C
      DO 3000 J = LB1,KB1
      IV = VREG(J)
      CALL UNPACK(IV)
      CALL FIBAN(2)
      IROWP = 0
      IRCMIN = -999999
      DO 2100 I = 1,NROW
      IF ( ABS(Y(I)) .LE. ZTOLPV) GO TO 2100
      IF (HREG(I) .GE.0) GO TO 2100
      IF (HREG(I) .LE. IRCMIN) GO TO 2100
      IRCMIN = HREG(I)
      IROWP = I
 2100 CONTINUE
      IF (IROWP .GT. 0) GO TO 2150
      IF(K2.EQ.1)PRINT 8000
      KINBAS(IV) = 0
      GO TO 3000
C
 2150 INCP = HREG(IROWP) + 3
C
C                       WRITE L AND U ETAS
C
      IF (J .EQ. KB1) GO TO 2160
      NELEM = NELEM + 1
      IF(NELEM) = IROWP
      E(NELEM) = Y(IROWP)
 2160 DO 2300 I = 1,NROW
```

```
      IF (I .EQ. IROWP) GO TO 2300
      IF( ABS(Y(I)) .LE. ZTOLZE) GO TO 2300
      IF (HREG(I) .GE. 0) GO TO 2200
C
C                    L ETA ELEMENTS
C
      NELEM = NELEM + 1
      IE(NELEM) = I
      E(NELEM) = Y(I)
      GO TO 2300
C
C                    U ETA ELEMENTS
C
 2200 IE(NELAST) = I
      E(NELAST) = Y(I)
      NELAST = NELAST - 1
      NUELEM = NUELEM + 1
 2300 CONTINUE
C
      JH(IROWP) = IV
      KINBAS(IV) = IROWP
      NUETA = NUETA + 1
      IE(NELAST) = IROWP
      IF (J .NE. KR1) GO TO 2330
      E(NELAST) = Y(IROWP)
      GO TO 2340
 2330 E(NELAST) = 1.
      NETA = NETA + 1
      LE(NETA+1) = NELEM + 1
 2340 NUELEM = NUELEM + 1
      LE(NTLAST) = NELAST
      NELAST = NELAST - 1
      NTLAST = NTLAST - 1
C
C                    UPDATE ROW COUNTS
C
      DO 2350 I = 1,NROW
      IF ( ABS(Y(I)) .LE. ZTOLZE) GO TO 2350
      IF (HREG(I) .GE. 0) GO TO 2350
      HREG(I) = HREG(I) - INCR
      IF (HREG(I) .GE. 0) HREG(I) = -1
 2350 CONTINUE
      HREG(IROWP) = 0
 3000 CONTINUE
C
C                    MERGE L AND U ETAS
C
 3500 NLETA = NETA
      NETA = NLETA + NUETA
      NLELEM = NELEM
      NELEM = NLELEM + NUELEM
      IF (NUELEM .EQ. 0) GO TO 3550
      CALL SHFTE
C
C                    INSERT SLACKS FOR DELETED COLUMNS
C
 3550 DO 3600 I = 1,NROW
      IF (JH(I) .NE. 0) GO TO 3600
```

```
      JH(I) = I
      IROWP = I
      CALL UNPACK(I)
      CALL FTRAN(1)
      CALL WRETA
 3600 CONTINUE
C
C                       UPDATE X
C
      CALL SHIFTR(1,3)
      CALL FTRAN(1)
      CALL SHIFTR(3,2)
C
C                       PRINT STATISTICS
C
      NOFD = NELEM - NETA
      NSTR = NROW - NSLCK
      IF(K3.NE.1)RETURN
      WRITE(6,500)NBNONZ,NSTR,NABOVE,NBELOW,NLELEM,NLETA,NUELEM,NUETA,
     1NOFD,NETA
  500 FORMAT(18H0INVERT STATISTICS/1H ,I4,14H NONZ IN BASIS/1H ,I4,
     128H STRUCTURAL COLUMNS IN BASIS/1H ,I4,19H VECTORS ABOVE BUMP/1H ,
     2I4,19H VECTORS BELOW BUMP/3H L:,I5,5H NONZ,I5,5H ETAS/3H U:,I5,
     35H NONZ,I5,5H ETAS/8H TOTALS:,I5,14H OFF DIAG NONZ,I5,5H ETAS )
C
      RETURN
      END
```

```
      SUBROUTINE SHFTE
C
      COMMON/WORK1/B(430),X(430),Y(430),YTEMP(430),A(3700),E(5700),
     1IA(3700),IE(5700),LA(1302),LE(2002),ICNAM(1302,2),KINBAS(1302),
     2 JH(430),ISTYPE(430),NAME(20),NTEMP(20),CMIN,COND,ERMAX,IFFEZ,
     3  INVFRQ,IOBJ,IPOWR,ITCH,ITCHA,ITCNT,ITHFRQ,IVIN,IVOUT,JCOLP,KINP,
     4  XSTAT,NROW,NCOL,NELEM,NETA,NLELEM,NLETA,NGELEM,NGETA,NUELEM,
     5  NUETA,SUMINF,K3
      COMMON/BLOCK/ ZTOLZE,ZTOLPV,ZTCOST,NRMAX,NTMAX,NEMAX,QRO,QMA,QBA,
     1  QFI,QFC,QBL,QPL,QMT,QA,QB,QC,QE,QF,QG,QH,QI,QL,QM,QN,QO,QR,QU,QZ
      DIMENSION BUDG(36),DD(36),FU(36),UPSP(36),URPIPE(36)
C
C                   SHIFT IE AND E OF U ELEMENTS
C
      NF = NEMAX - NUELEM + 1
      INCR = 0
      DO 1000 I = NF,NEMAX
      INCR = INCR + 1
      IE(NLELEM + INCR) = IE(I)
      E(NLELEM + INCR) = E(I)
 1000 CONTINUE
C
      IDIF = NEMAX - NLELEM - NUELEM
      NF = NTMAX - NUETA + 1
      INCR = 0
      DO 2000 I = NF,NTMAX
      INCR = INCR + 1
      LE(NLETA + INCR) = LE(I) - IDIF
 2000 CONTINUE
      LE(NETA+1) = NELEM + 1
      RETURN
      END
```

```
SUBROUTINE GETPHI(I,J,X,F)
RETURN
END
```

```
      FUNCTION FUNCT1(A,I)
      IF(I.GE.2) GO TO 10
      FUNCT1=1.
      RETURN
10    FUNCT1=1.
      I=I-1
      DO 20 J=1,I
   20 FUNCT1=FUNCT1+(1.-A)** J
      I=I+1
      RETURN
      END
```

```
      FUNCTION FUNCT2(A,I)
      IF(I.GE.2) GO TO 10
      FUNCT2=0.
      RETURN
   10 FUNCT2=0.
      I=I-1
      DO 20 J=1,I
   20 FUNCT2=FUNCT2+FLOAT(J)*((1.-A)**(I-J)    )
      I=I+1
      RETURN
      END
```

```
      FUNCTION FUNCT3(A,B,I)
      IF(I.GE.1)GO TO 10
      FUNCT3=0.
      RETURN
   10 FUNCT3=0.
      DO 20 J=1,I
   20 FUNCT3=FUNCT3+((1.-A)**(I-J))*FUNCT1(B,J)
      RETURN
      END
```

```
      FUNCTION FUNCT4(A,B,I)
      FUNCT4=0.
      IF(I.LT.1)RETURN
      DO 20 J=1,I
   20 FUNCT4=FUNCT4+((1.-A)**(I-J))*FUNCT2(B,J)
      RETURN
      END
```

```
      FUNCTION FUNCT5(DW,DS,NPURCH)
      IF(NPURCH-1)10,20,30
   10 FUNCT5=0.
      RETURN
   20 FUNCT5=1.
      RETURN
   30 LL=0
      LU=NPURCH-1
      FUNCT5=0.
      DO 40 I=LL,LU
   40 FUNCT5=FUNCT5+((1.-DW)**(NPURCH-1-I))*((1.-DS)**I)
      RETURN
      END
```